Tevatron Operations

Ron Moore

DOE Tevatron Operations Review

SC-1 Breakout

March 21, 2006

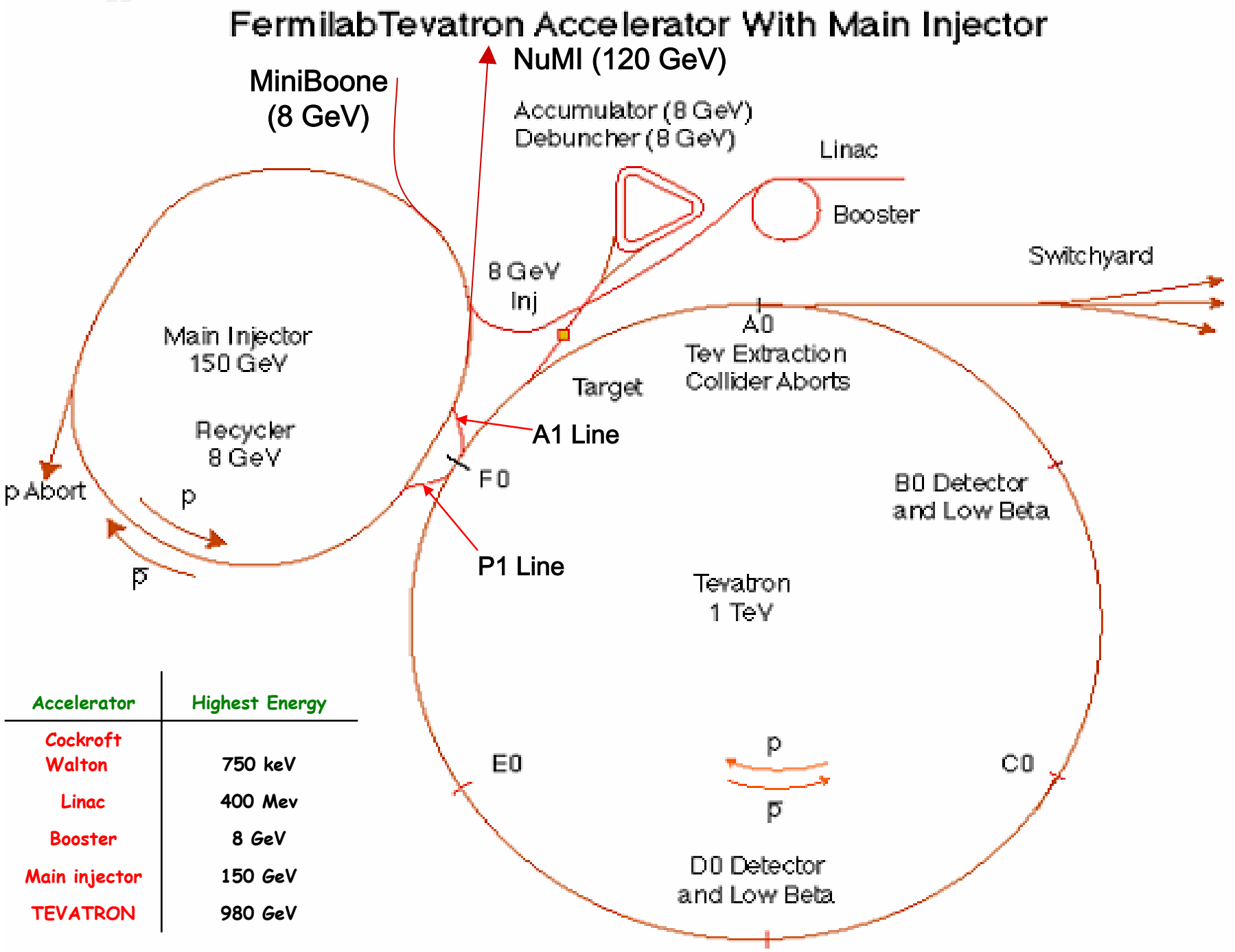
Breakout Session Agenda

- Tevatron Overview – Ron Moore
- Beam-Beam Effects + Orbit Helix – Yuri Alexahin
- Simulations, Chromatic Compensation, New Working Points – Alex Valishev

Tevatron Overview (this presentation)

- Operations Overview
- Instrumentation
- TEL Progress
- Separator Progress
- Shutdown Tasks

Operations Overview



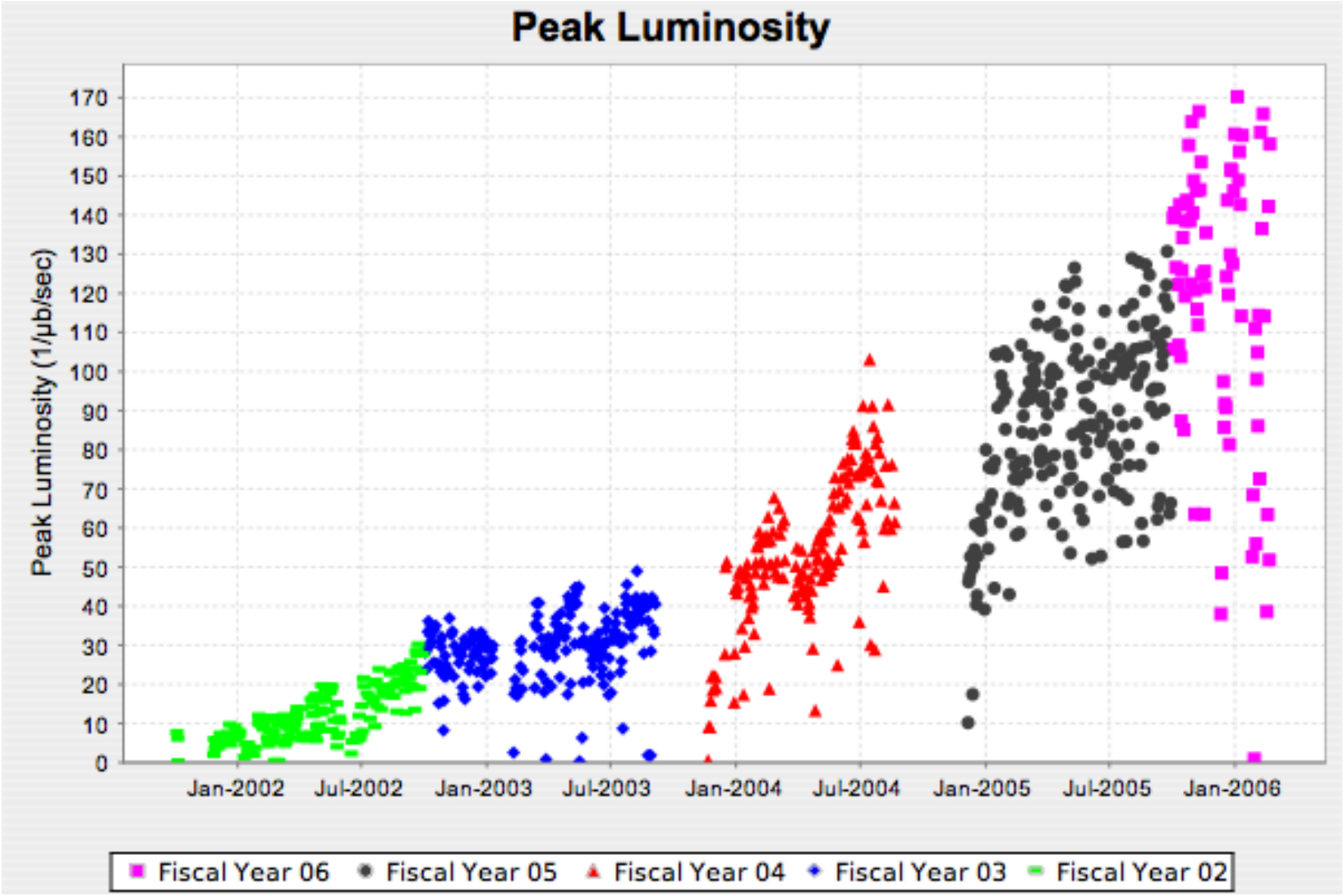
Accelerator	Highest Energy
Cockroft Walton	750 keV
Linac	400 Mev
Booster	8 GeV
Main injector	150 GeV
TEVATRON	980 GeV

Since the last long shutdown ended (12/04)…

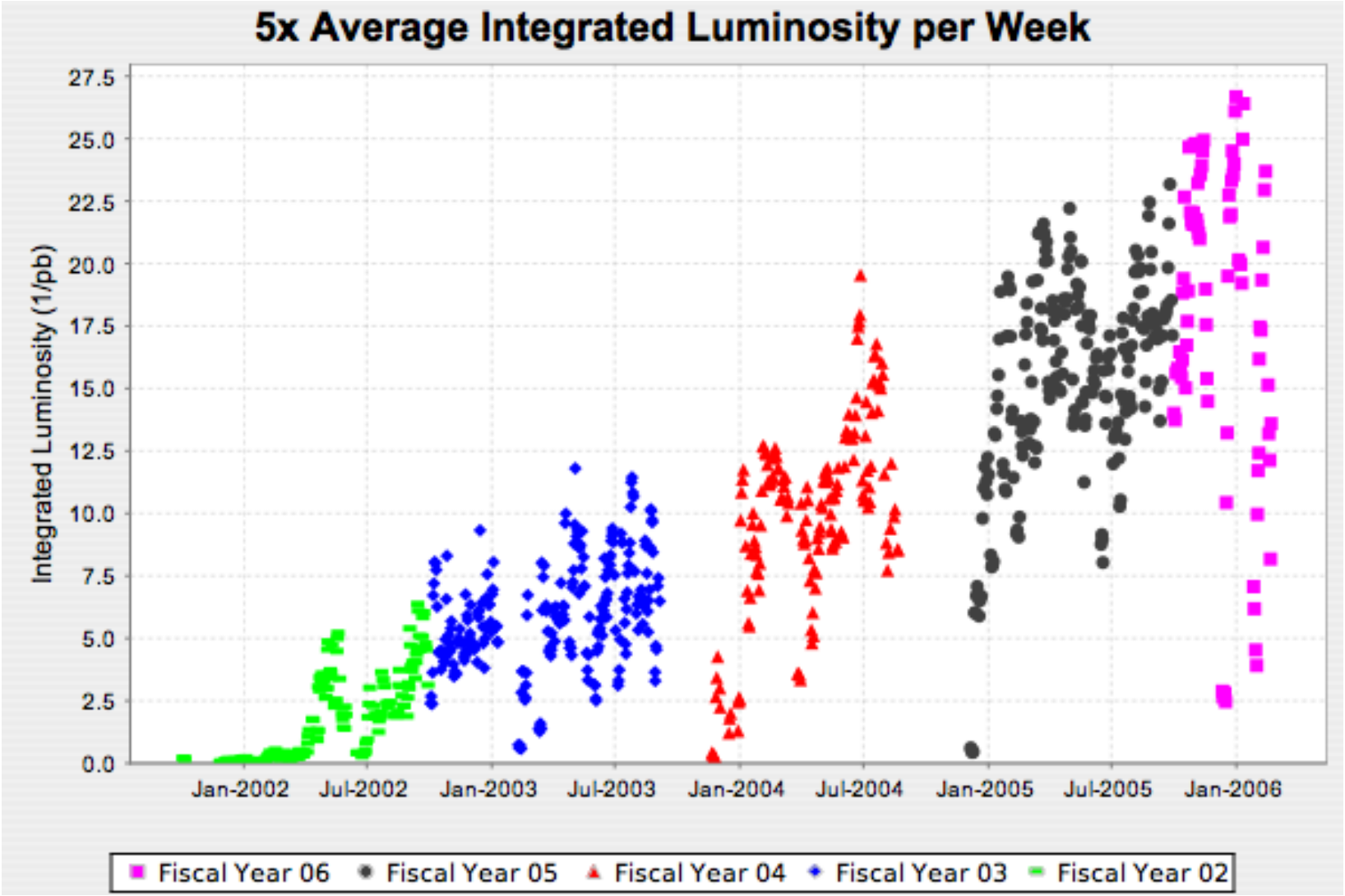
- 287 HEP stores begun (give/take a few…not counting ones lost before HEP)
- Record initial lumi improved from 103 to 172 (10)^{30} cm^{-2} s^{-1}
- Record weekly integrated luminosity up to 24.4 pb^{-1}
- Delivered over 850 pb^{-1} of data
  - Both CDF & D0 have recorded > 1.4 fb^{-1} of data each in Run II

- 28 cm β* and Recycler-only pbars boost Tevatron luminosity
- Periods of outstanding reliability + 3 recent failures

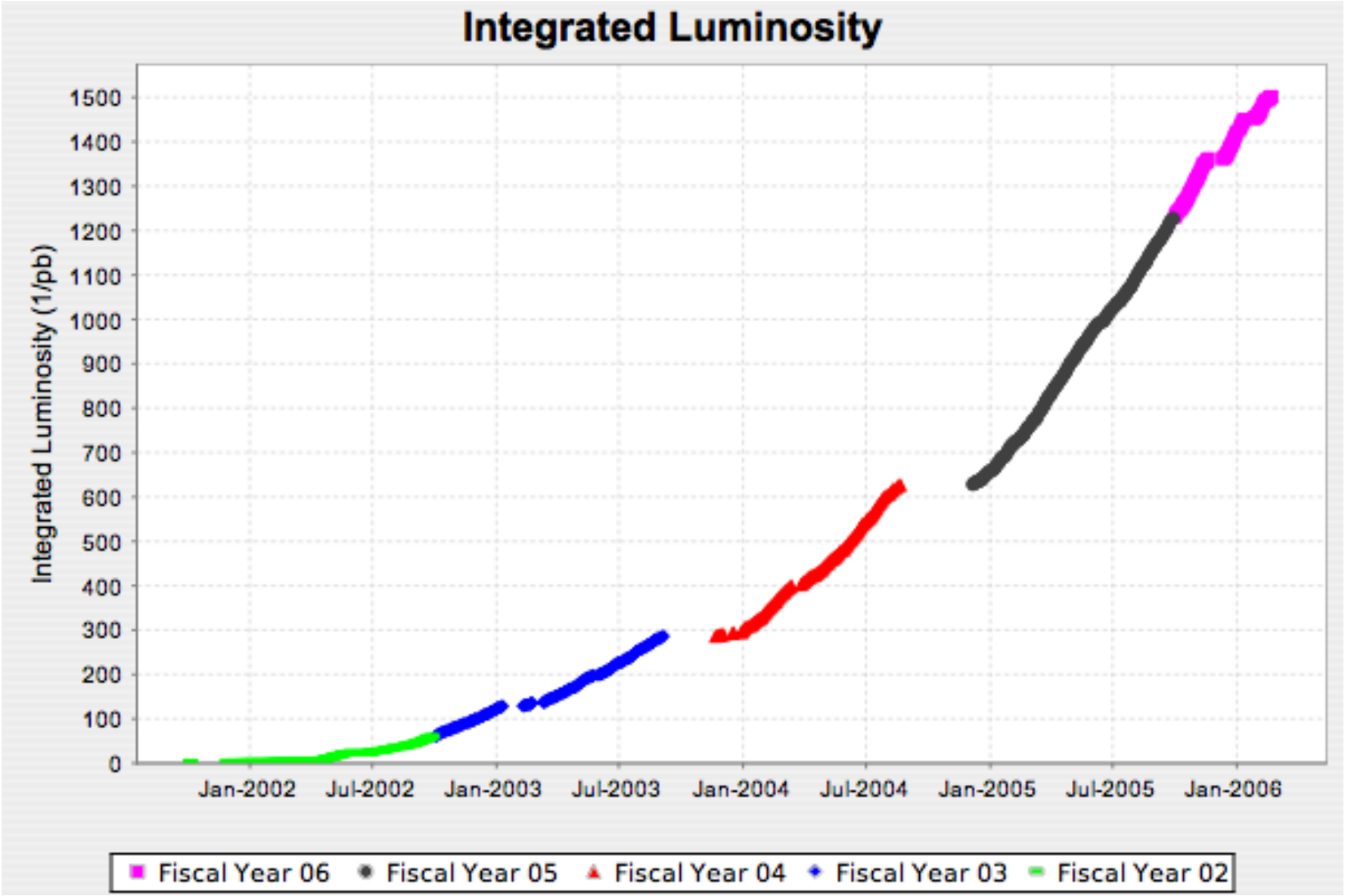
Peak Luminosity



Integrated Luminosity per Week



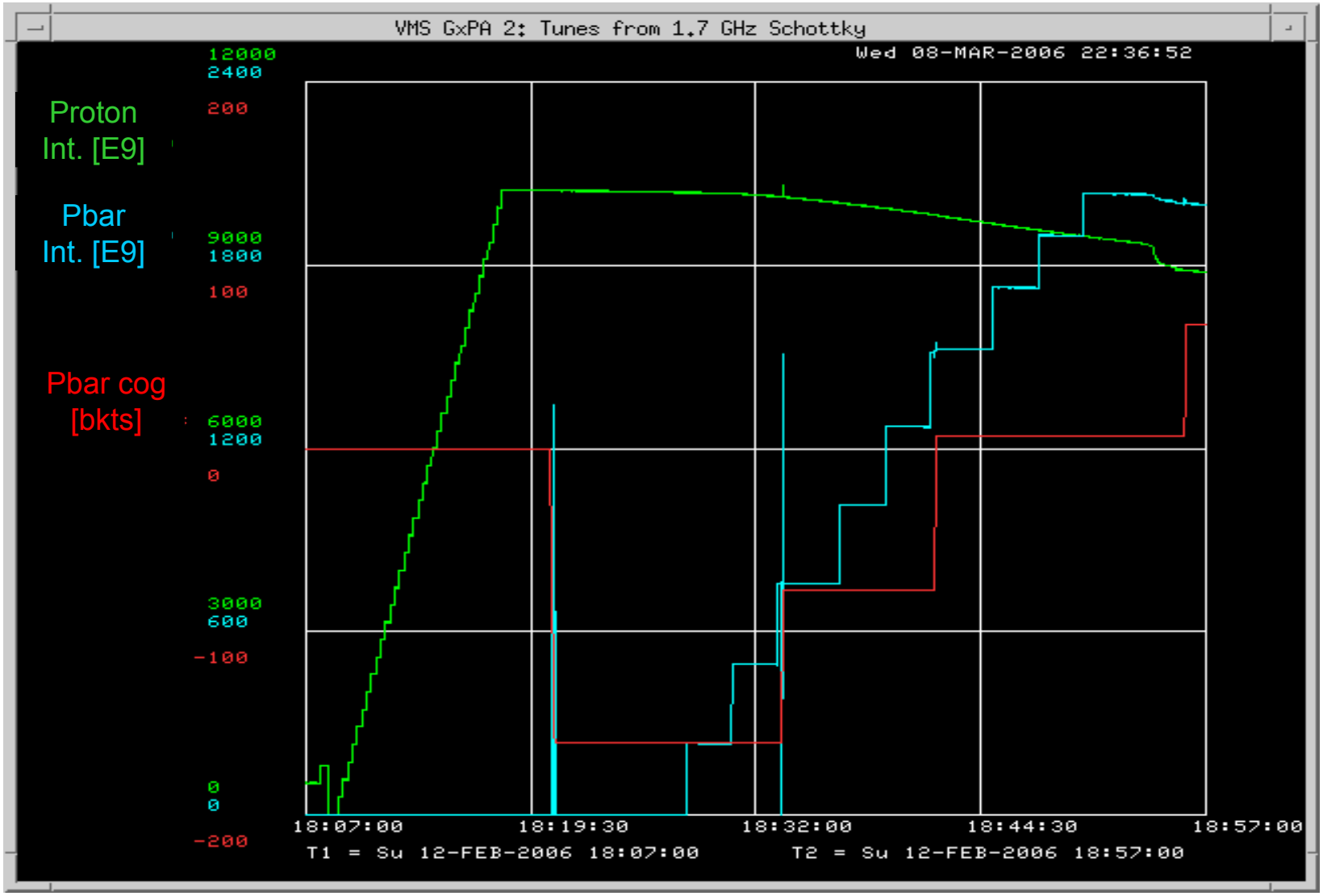
Integrated Luminosity



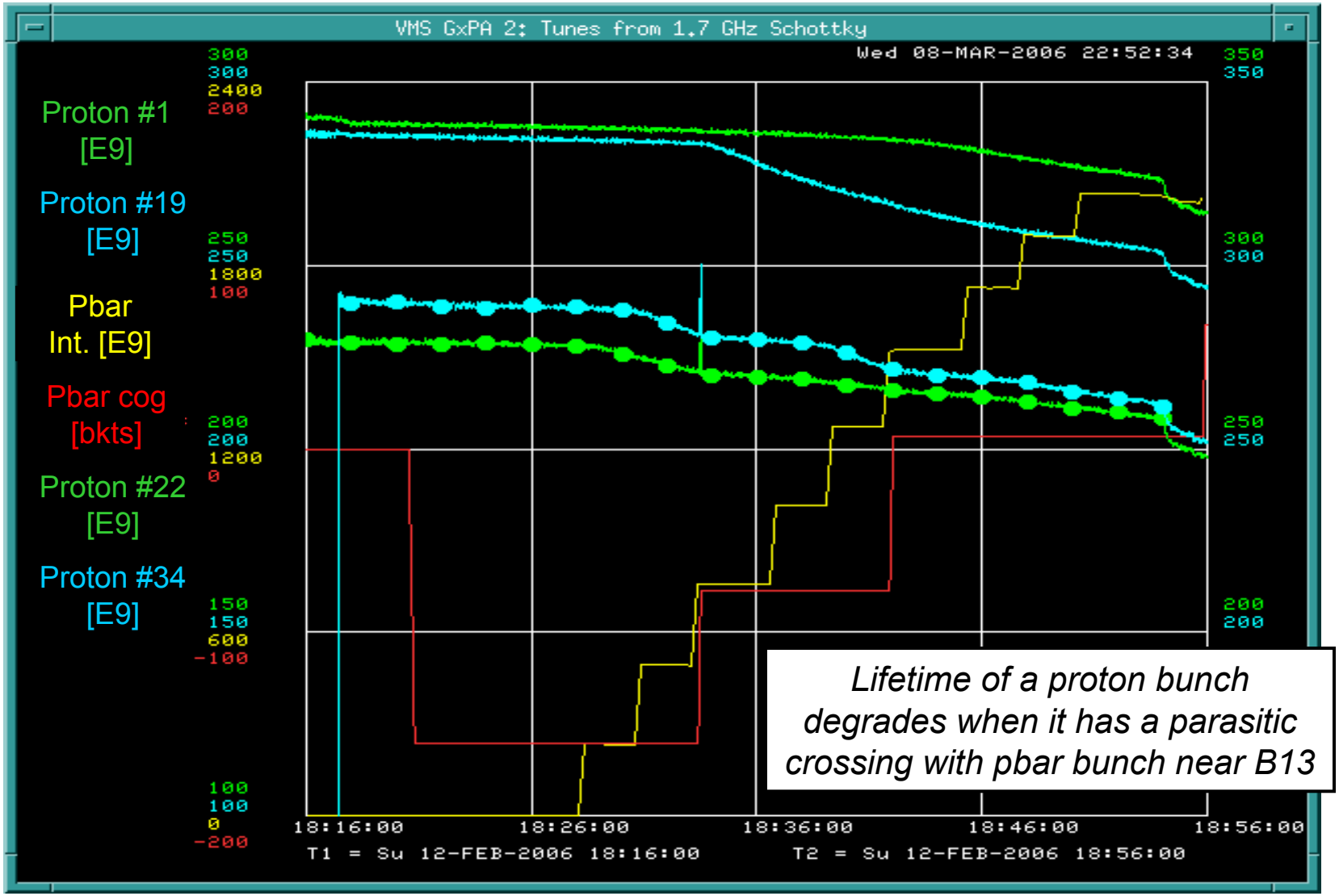
Tevatron Improvements

- Installing/commissioning new BPM electronics completed
- 28 cm β* + optics correction
  - Lattice measurements exploited new BPM electronics
  - Tested at end of stores; implemented in September
- Pbar tune stabilization during HEP
  - Keep pbar tunes > 7/12 as beam-beam tune shift decreases
  - Helps maintain pbar lifetime
- Orbit stabilization during HEP
  - Compensate for "fast" low-beta quad motion
  - Eliminate halo spikes @ CDF & D0, maintain lifetime
- Longitudinal instabilities solved
  - Problem at last year's review – fixed damper hardware

Comfort Plot @ 150 GeV

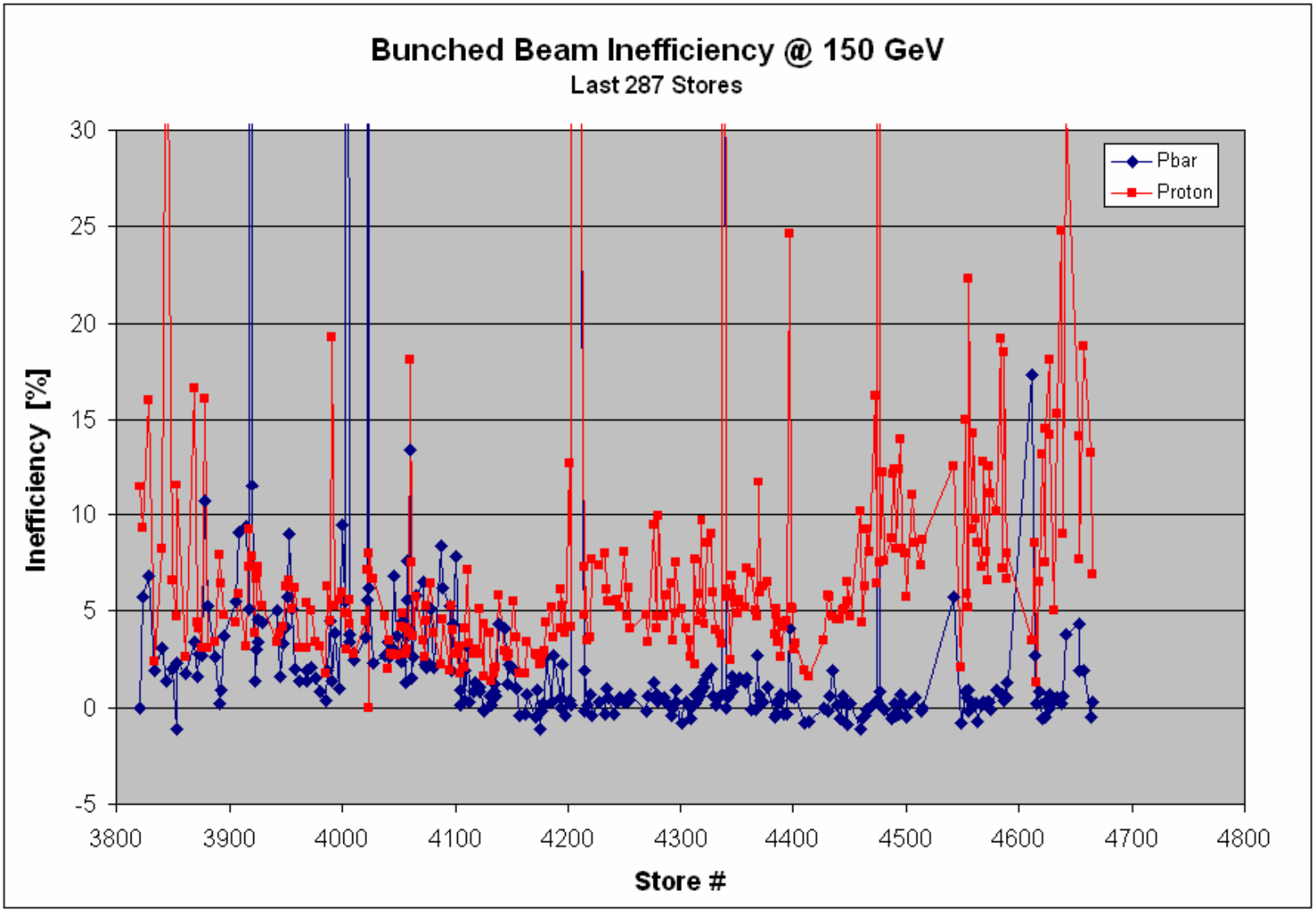


Bunch-by-Bunch Proton Losses

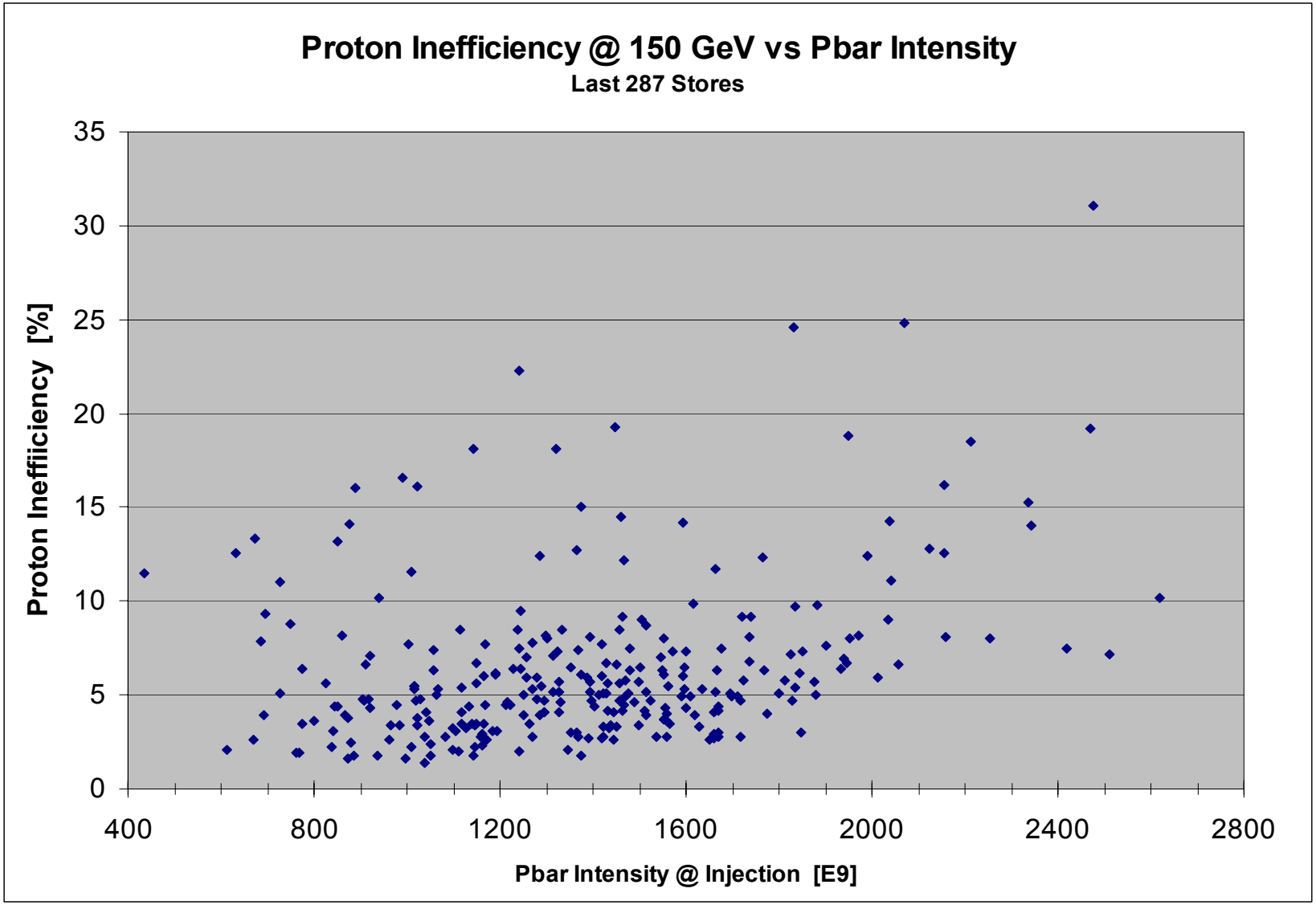


Lifetime of a proton bunch degrades when it has a parasitic crossing with pbar bunch near B13

Inefficiencies @ 150 GeV



Proton Inefficiency @ 150 GeV vs Pbar Intensity

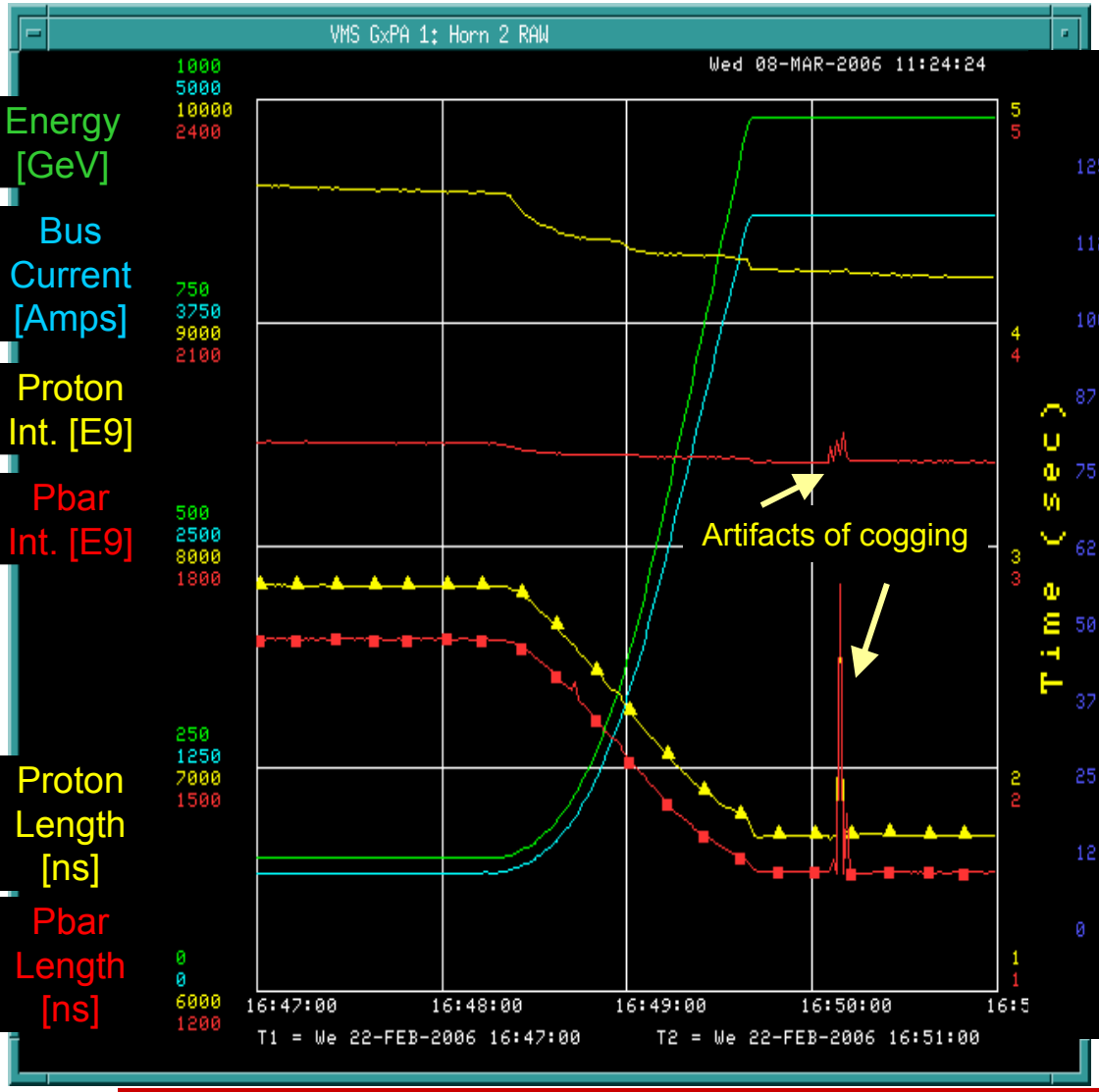


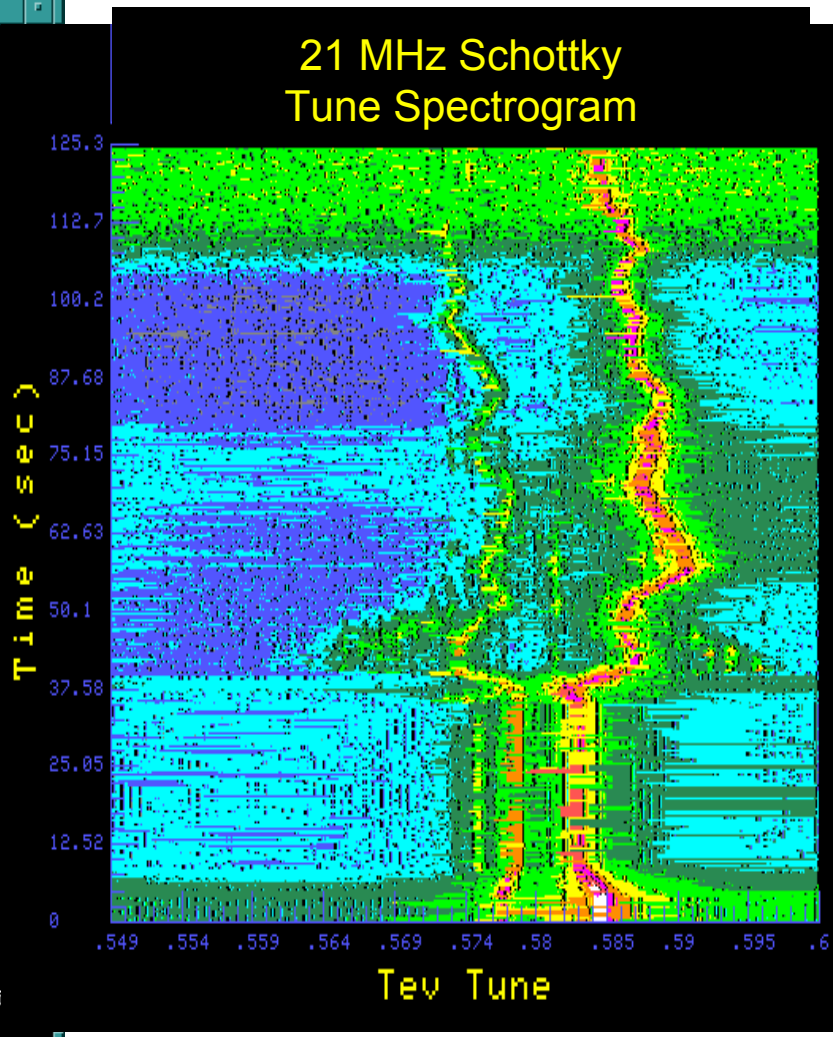
Ramp

- 150 → 980 GeV in 86 sec; max ramp rate is 16 GeV/s

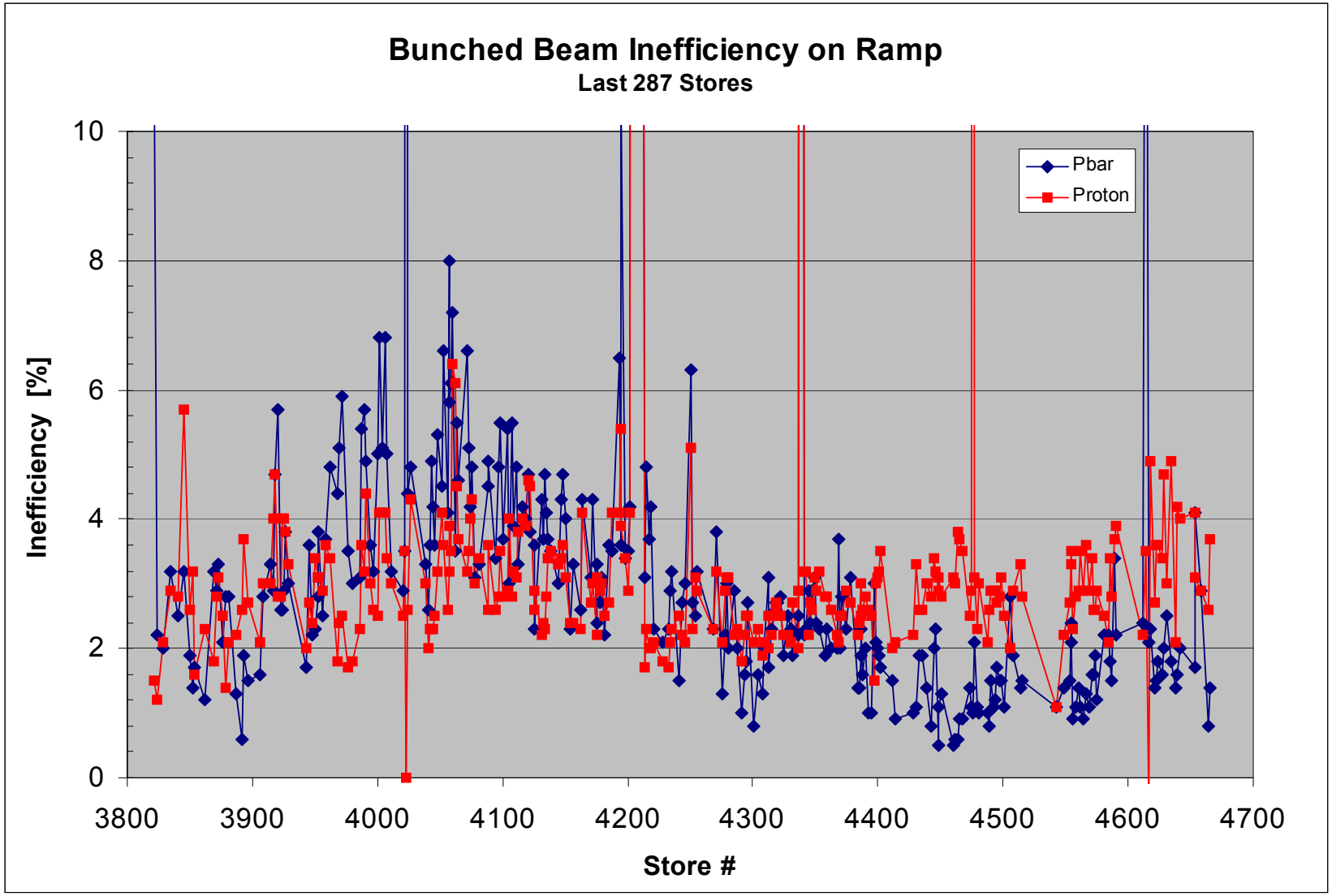
- 8 RF cavities – 4 proton + 4 pbar
  - Phased such that one beam sees no net voltage from other cavities
  - RF voltage is constant; bucket area minimum early in ramp
- Bunch lengths shrink by $(980/150)^{1/4} \approx 1.6$
  - e.g., protons: 2.8 ns → 1.7 ns
- Final pbar cogging done after reaching flattop
- Longitudinal damper (protons) off for acceleration, on after cog
- Beam separation decreases > 600 GeV
  - Can't run separators hard enough
  - Separation decreases faster than beam size

Up the Ramp


VMS GxPA 1: Horn 2 RAW
Wed 08-MAR-2006 11:24:24
Energy [GeV]
Bus Current [Amps]
Proton Int. [E9]
Pbar Int. [E9]
Proton Length [ns]
Pbar Length [ns]
1000
5000
10000
2400
750
3750
9000
2100
500
2500
8000
1800
250
1250
7000
1500
0
0
6000
1200
Artifacts of cogging
16:47:00
16:48:00
16:49:00
16:50:00
T1 = We 22-FEB-2006 16:47:00
T2 = We 22-FEB-2006 16:51:00


21 MHz Schottky
Tune Spectrogram
Time (sec)
125.3
112.7
100.2
87.68
75.15
62.63
50.1
37.58
25.05
12.52
0
.549
.554
.559
.564
.569
.574
.58
.585
.59
.595
Tev Tune

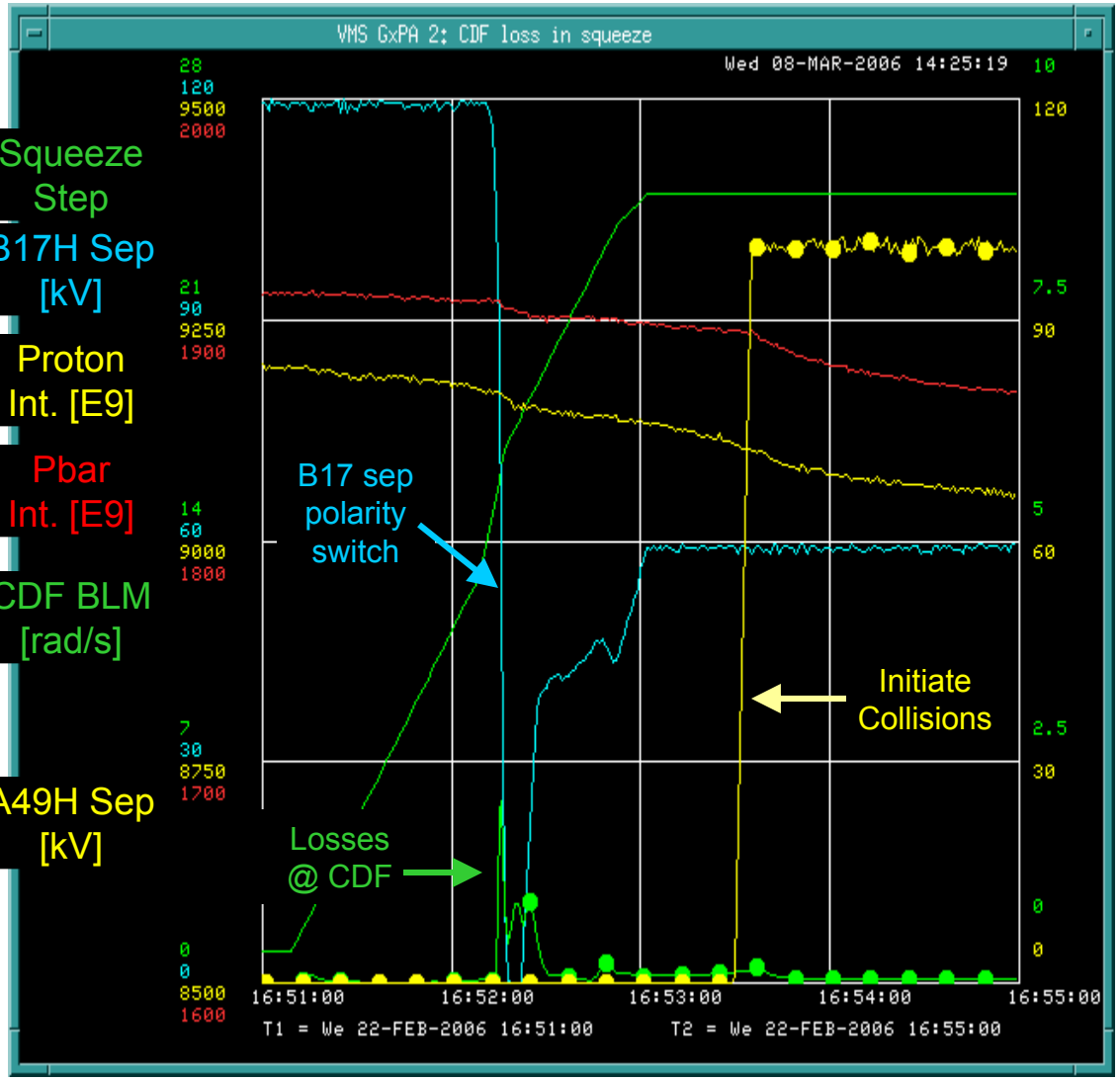
Ramp Inefficiencies

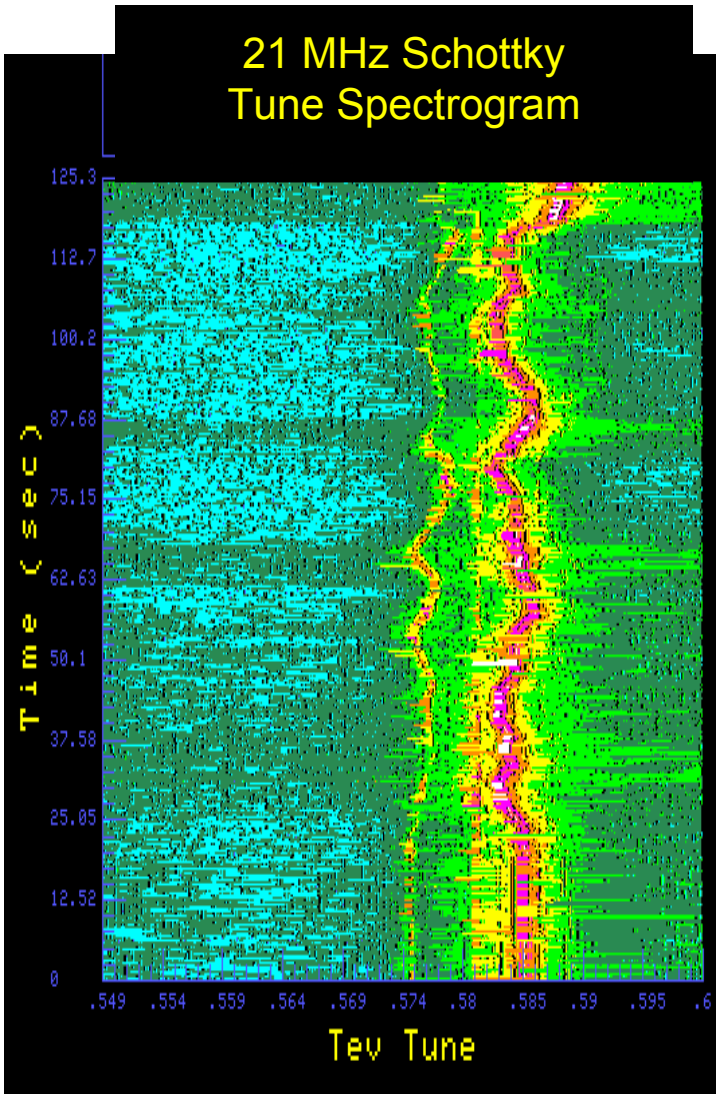


Squeeze

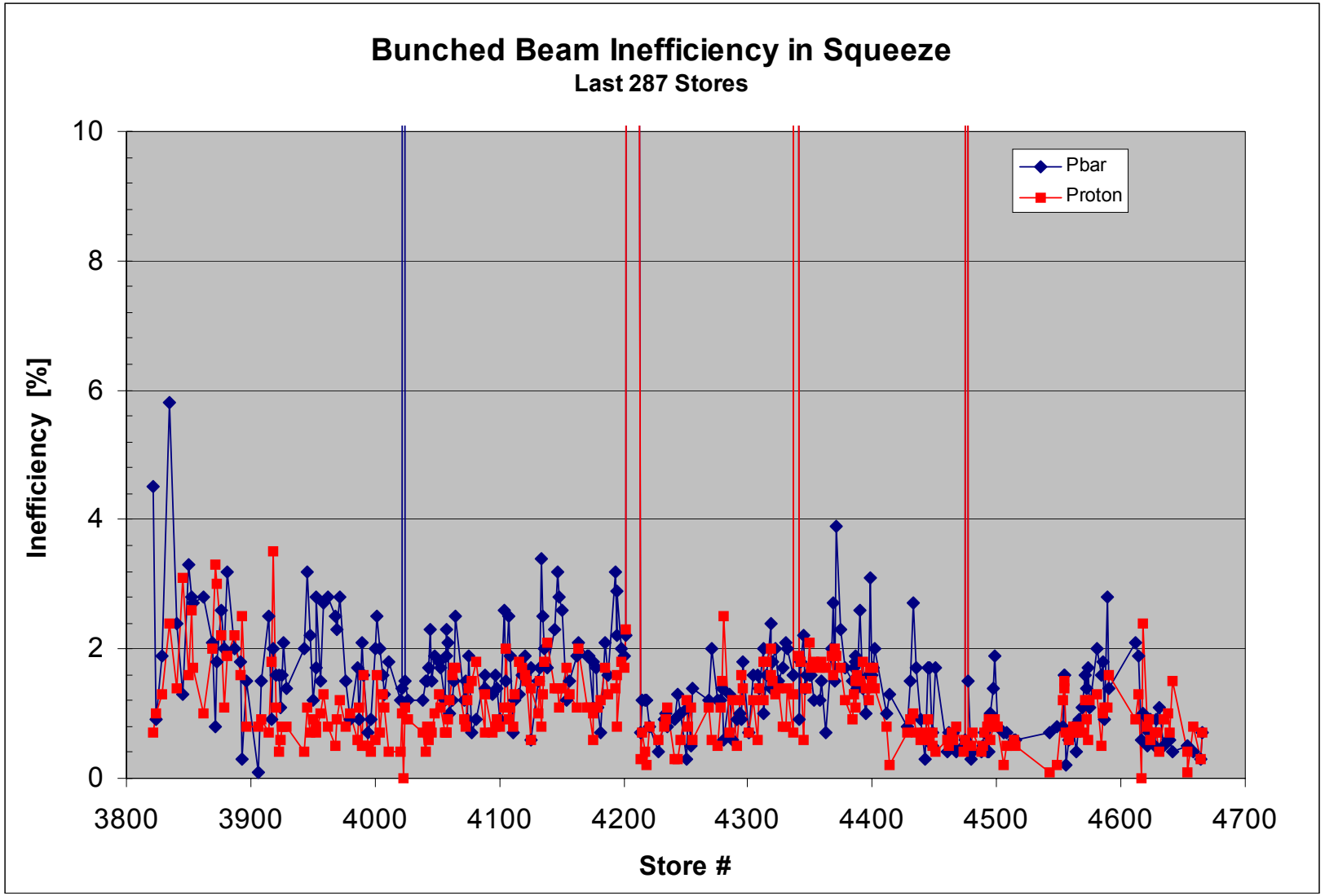
- Shrink the beams from 1.6 m → 28 cm β* at CDF and D0
- Take ≈125 sec to step through 14 different lattices
- Also need to switch polarity of B17 horz separator
  - Put pbars on "right" side for CDF pots for collisions
    - Injection helix → Collision helix
  - Horizontal separation minimum at that time
  - Several years ago, up to 25% pbars lost at that step
  - Yuri Alexahin developed new separator scheme to fix, but it's still difficult to transition
- 28 cm β* implemented in Sep 05 by Alex Valishev and Yuri
- Moved proton tunes > 7/12 (pbars already there)
  - Store-to-store pbar variations moved proton tunes around
  - Gain bit tune space, modest non-luminous lifetime improvement

Through the Squeeze

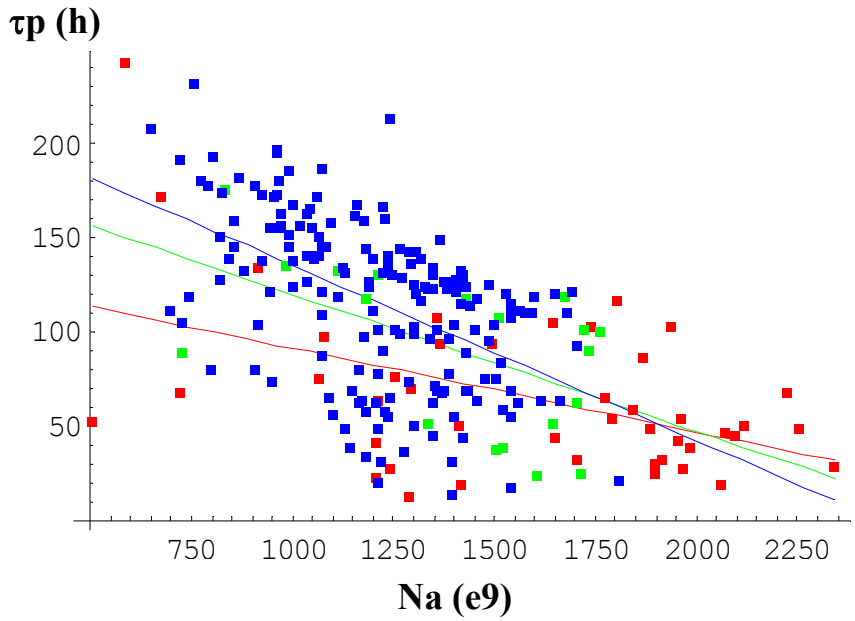




Squeeze Inefficiencies



BB-induced Proton Losses



β*=35cm, Qp<7/12

β*=28cm, Qp<7/12

β*=28cm, Qp>7/12

linear fits:

τp=228-0.093Na

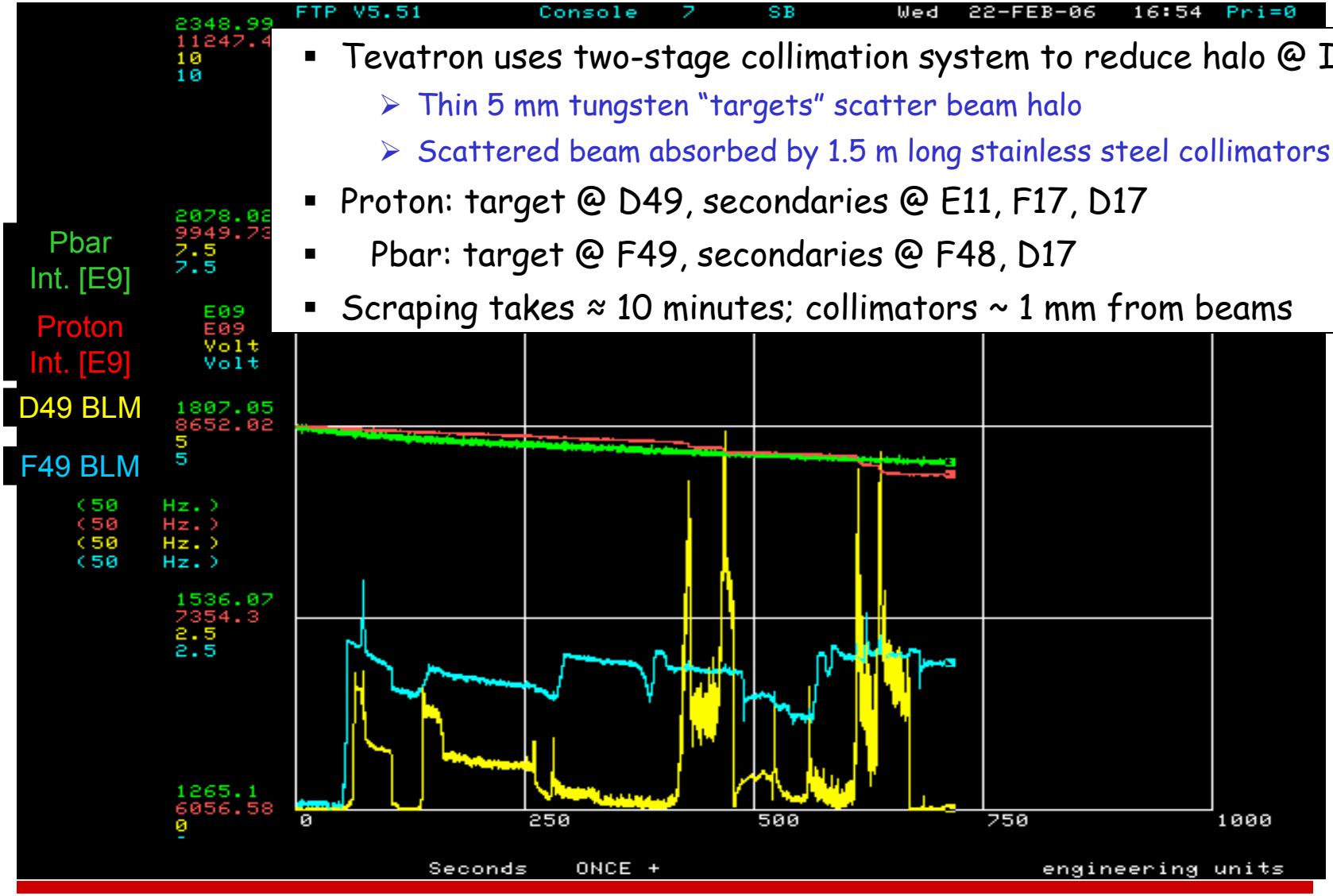
τp=192-0.073Na

τp=136-0.044Na

- Moving the proton tunes above 7/12 produced no big lifetime improvement due to store-to-store variation in tunes
- However, the slant down with increasing pbar intensity became less

Halo Removal, a.k.a. Scraping

- Tevatron uses two-stage collimation system to reduce halo @ IPs
  - Thin 5 mm tungsten "targets" scatter beam halo
  - Scattered beam absorbed by 1.5 m long stainless steel collimators
- Proton: target @ D49, secondaries @ E11, F17, D17
- Pbar: target @ F49, secondaries @ F48, D17
- Scraping takes ≈ 10 minutes; collimators ~ 1 mm from beams



Luminosity Formula

$$L = \frac{f N_p N_a}{2\pi(\varepsilon_p + \varepsilon_a)\beta^*} H(\sigma_z / \beta^*)$$

Increasing the Luminosity

- New 28 cm β* lattice
- Recycler-only pbars provide larger N_a + smaller ε_a

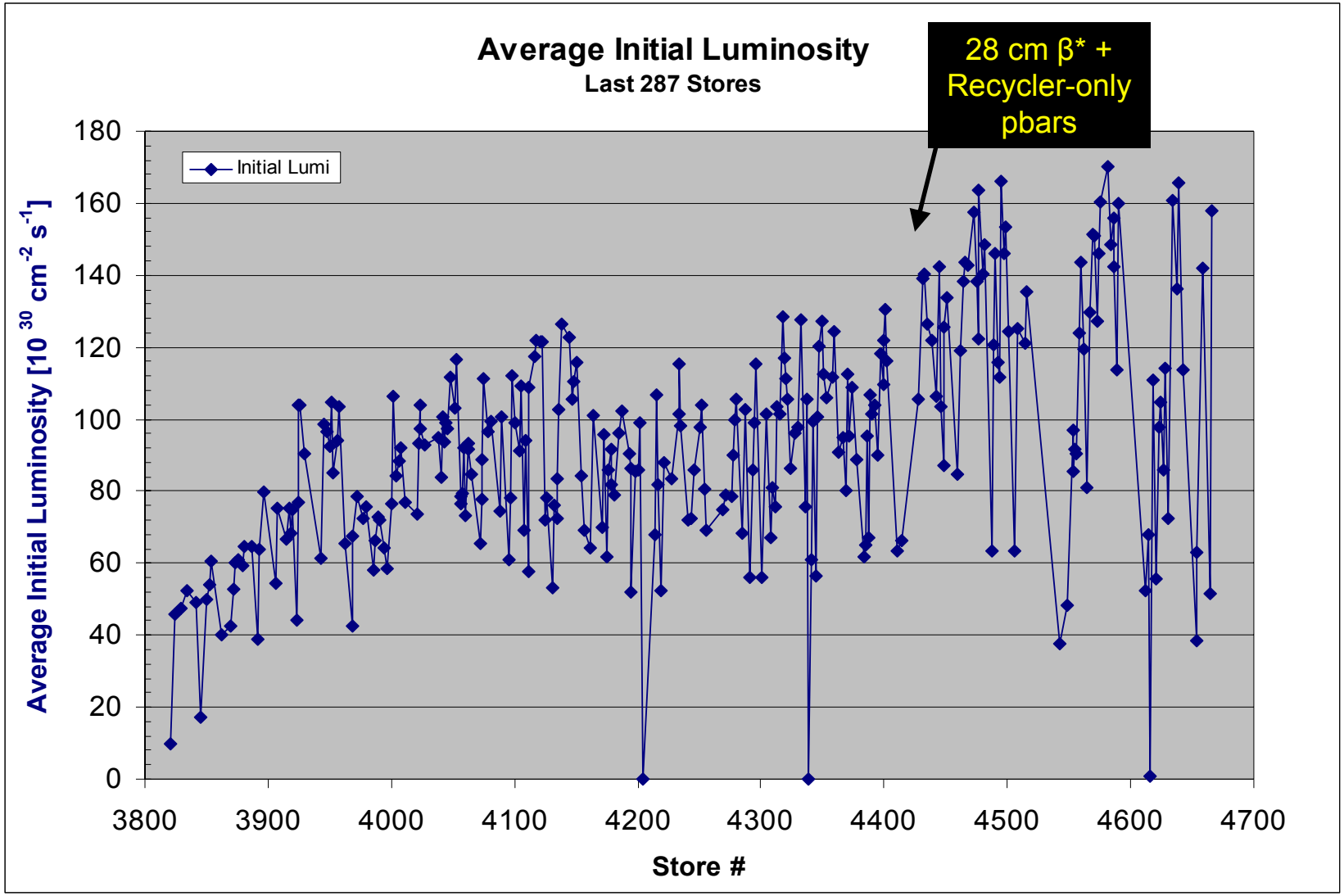
Effective Emittance

$$\varepsilon_{eff} = \frac{f N_p N_a H(\sigma_z / \beta^*)}{4\pi\beta^* L}$$

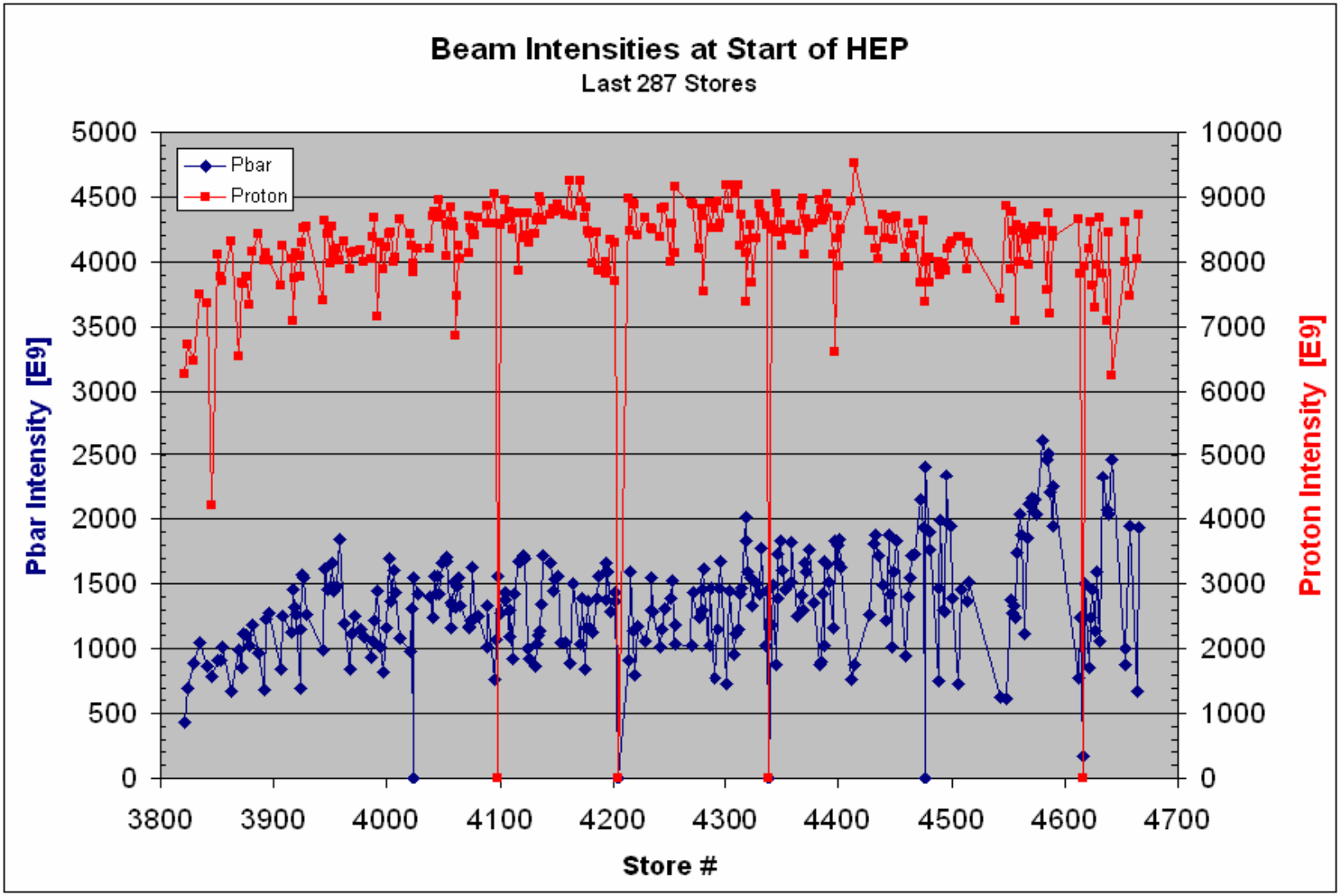
Specific Luminosity

$$L_{specific} = \frac{L}{N_p N_a}$$

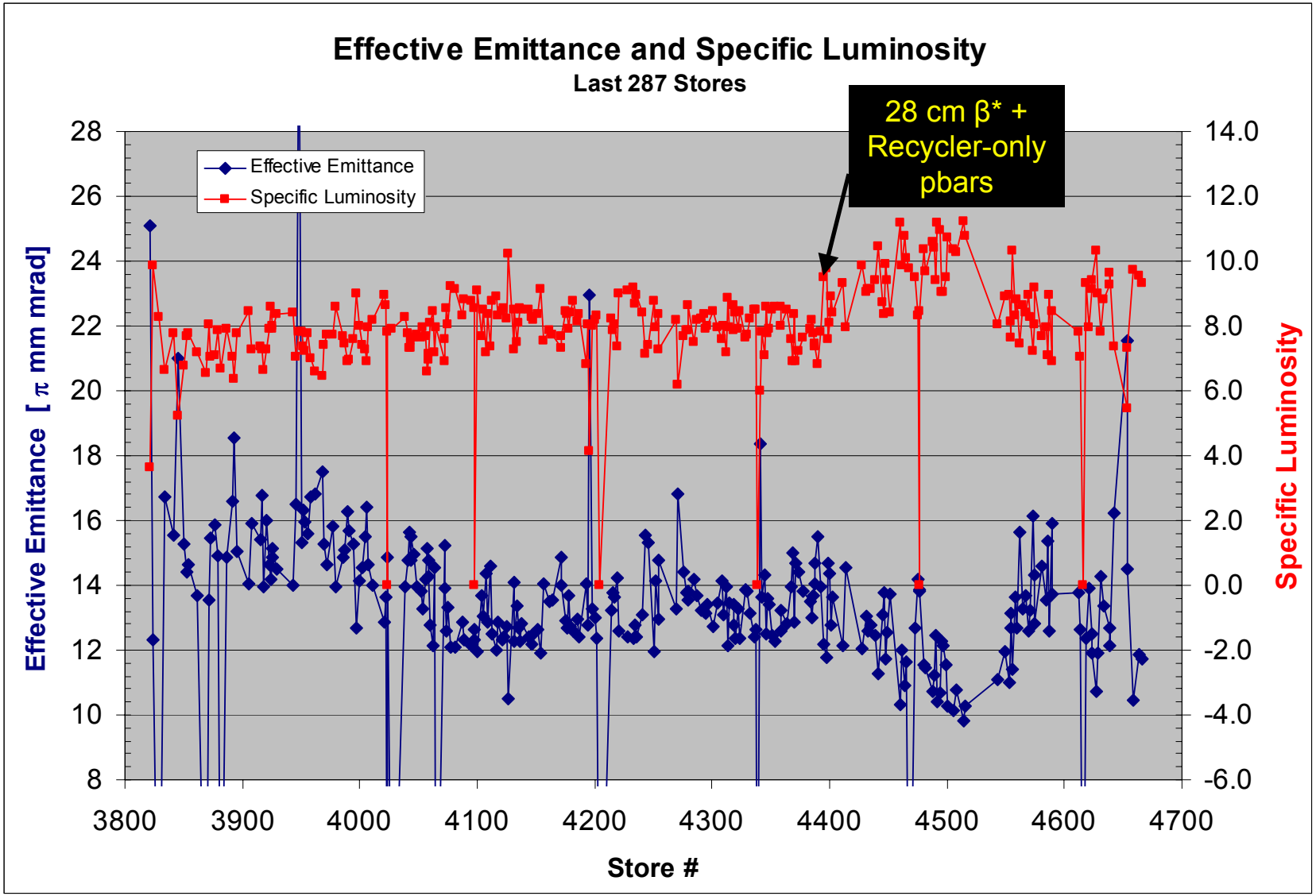
Initial Luminosities



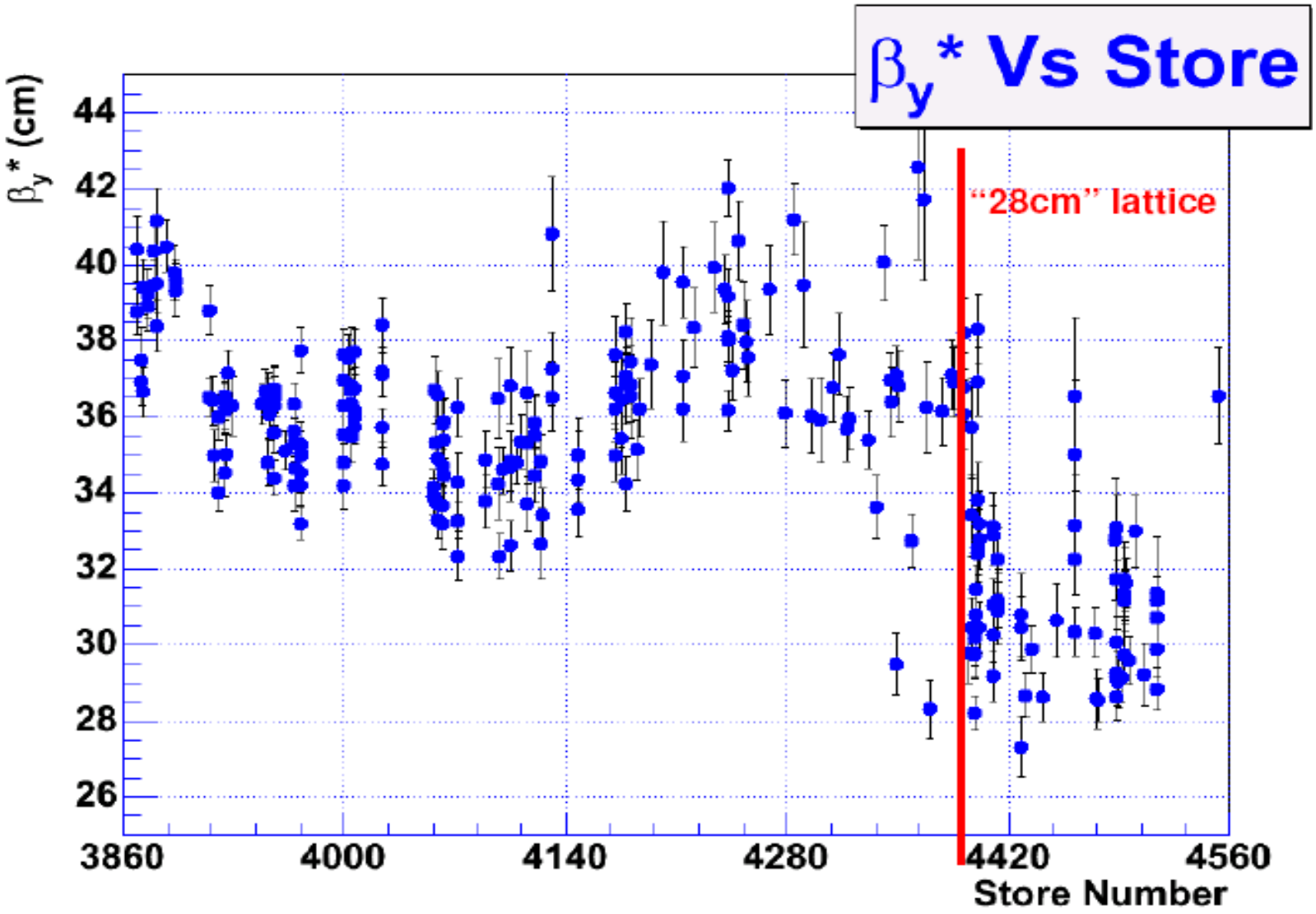
Beam Intensities @ HEP



How Much Bang for the Buck?



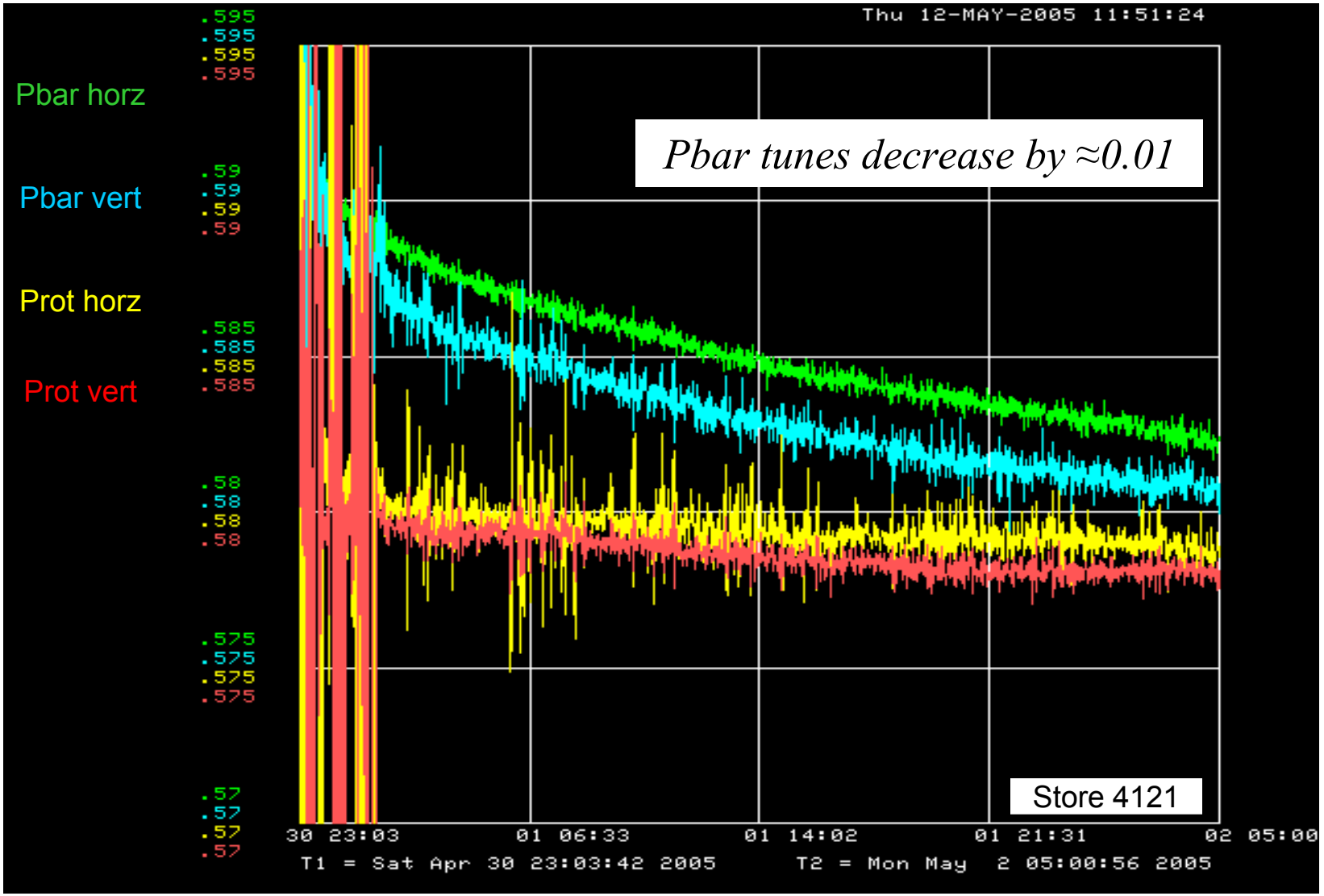
β* Measurements by D0



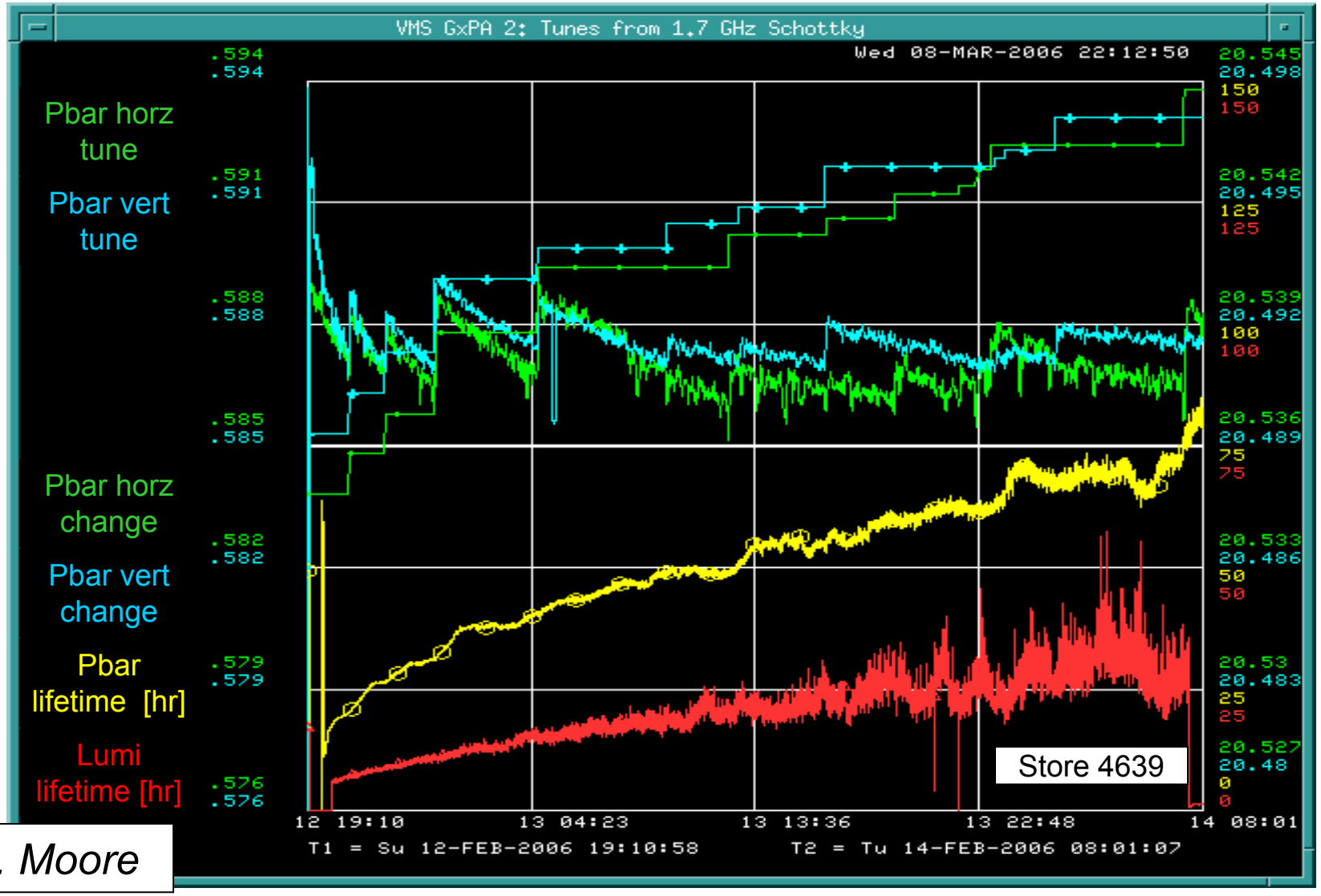
Pbar Tune Feedback

- Pbar tunes shifted up ~0.020 due to head-on and long-range beam-beam tune shifts
- Pbar tunes can decrease by ~0.01 over store as emittances grow
  - Reduced lifetime while crossing 7/12 resonance
- Maintain pbar lifetime by keeping tunes > 7/12
  - Monitor 1.7 GHz Schottky tune measurements
  - Post an alarm when tunes getting close to 7/12
  - MCR operators push tunes up with pbar-only tune mults
- Mechanism already in place for protons, too

Tunes without Compensation

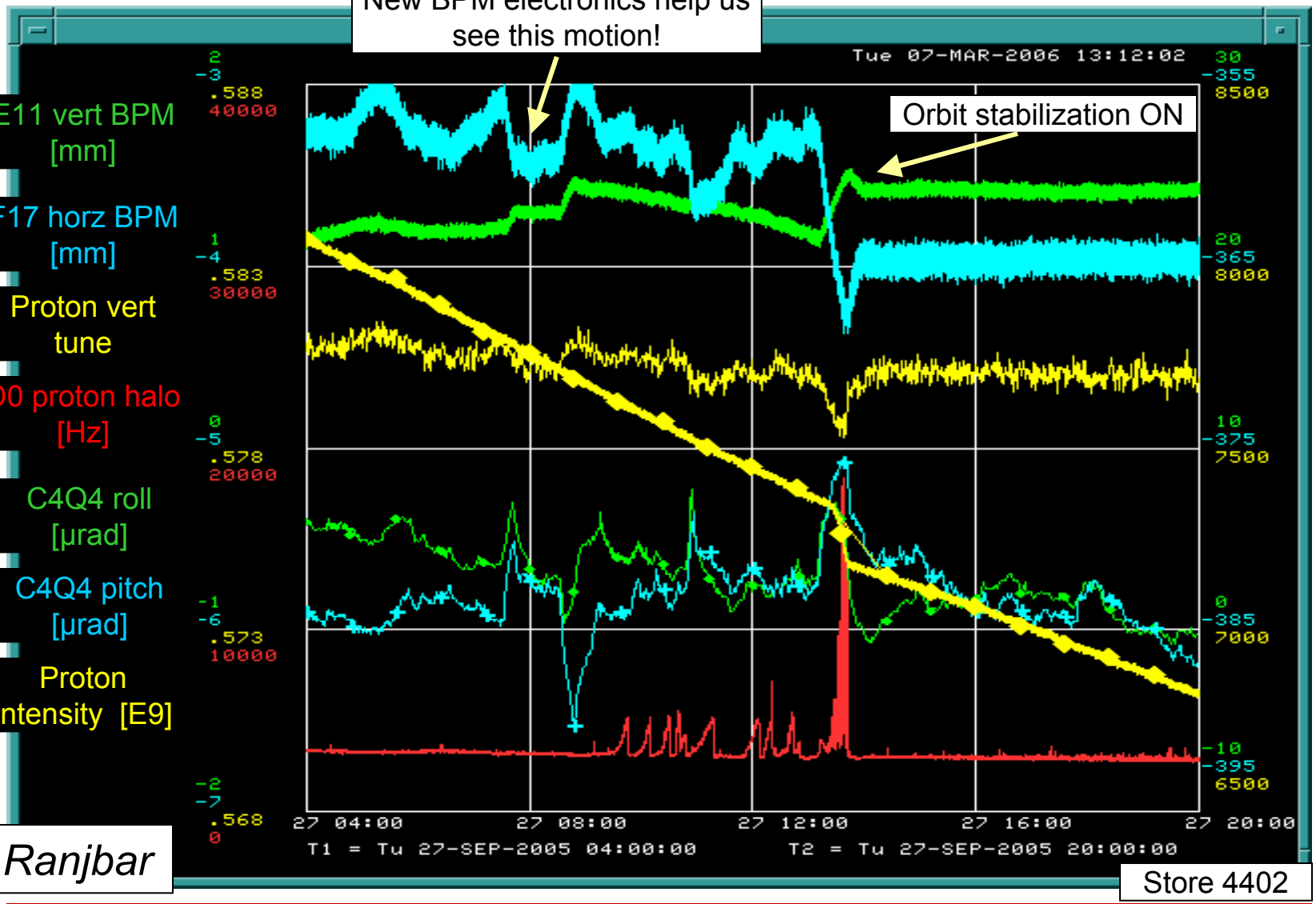


Pbar Tune Feedback



R. Moore

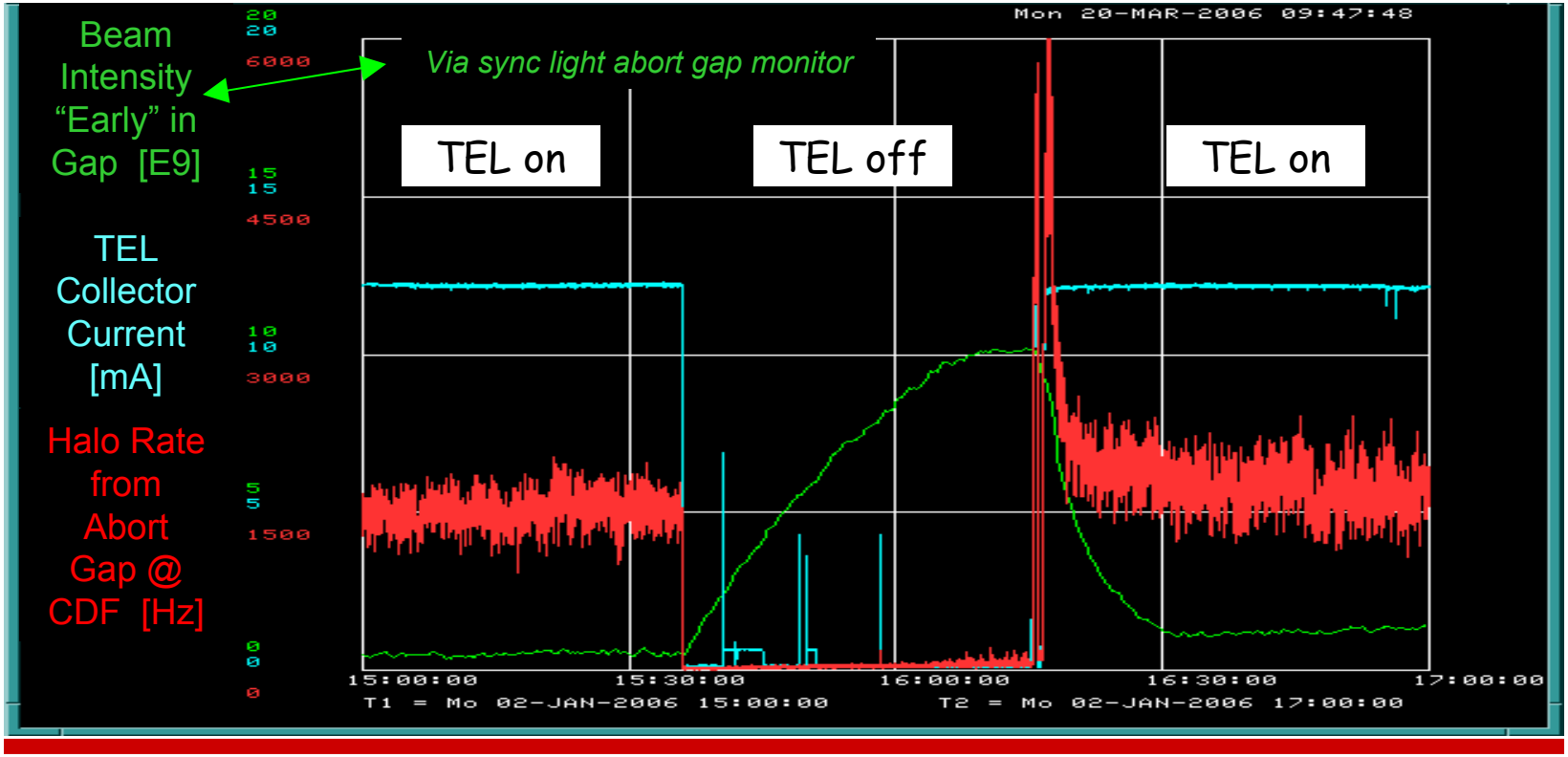
Magnet Motion / Orbit Stabilization



V. Ranjbar

TEL – Tevatron Electron Lens

- Continuously removes DC beam in abort gap
  - Beam in gap when abort kickers fire not kicked into dump
  - Can cause quenches and high doses in CDF
  - Periodic pulsing of e-beam drives beam toward tune resonances
- Additional status + Beam-Beam Compensation later…

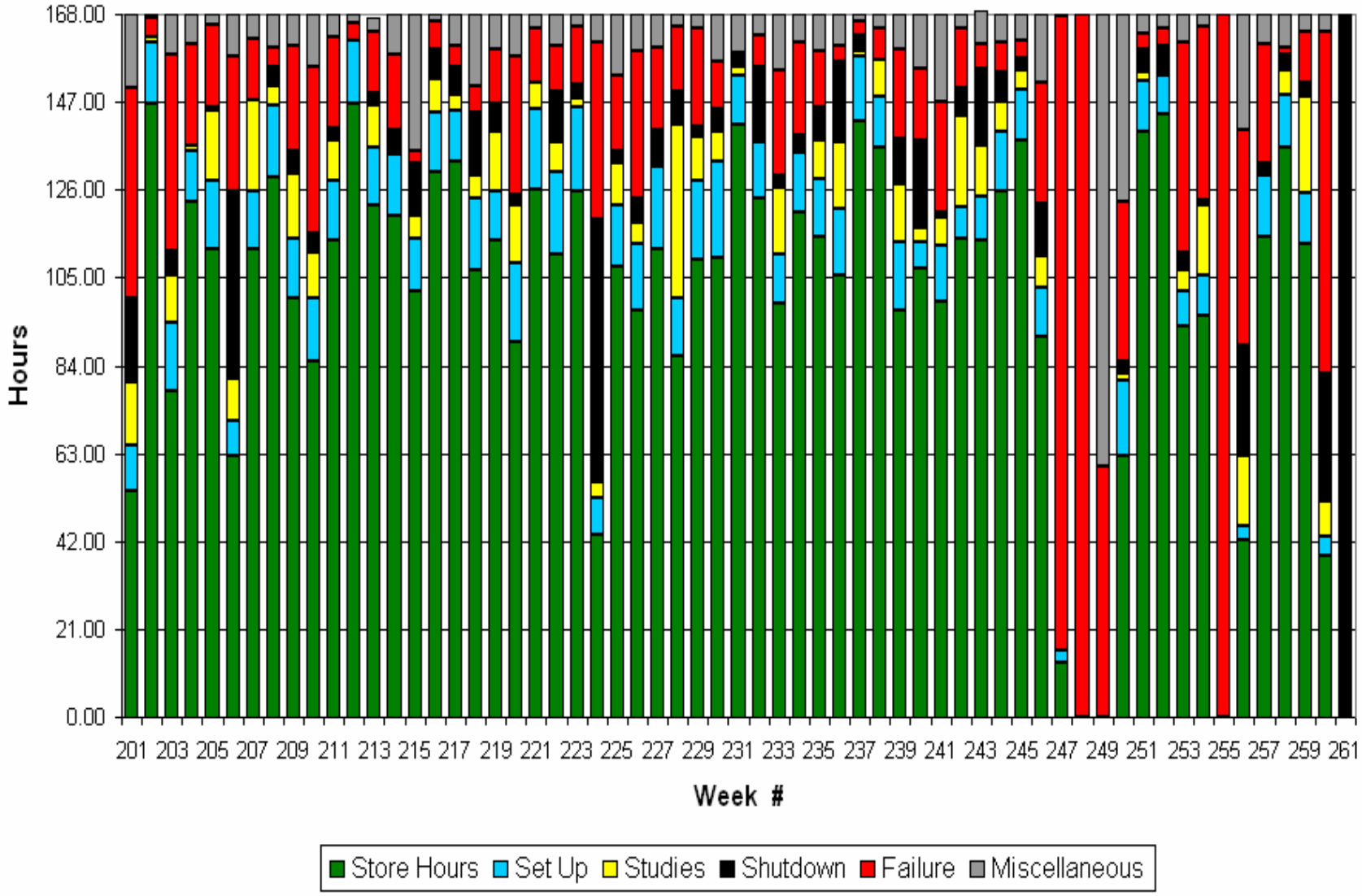


Low Luminosity Stores

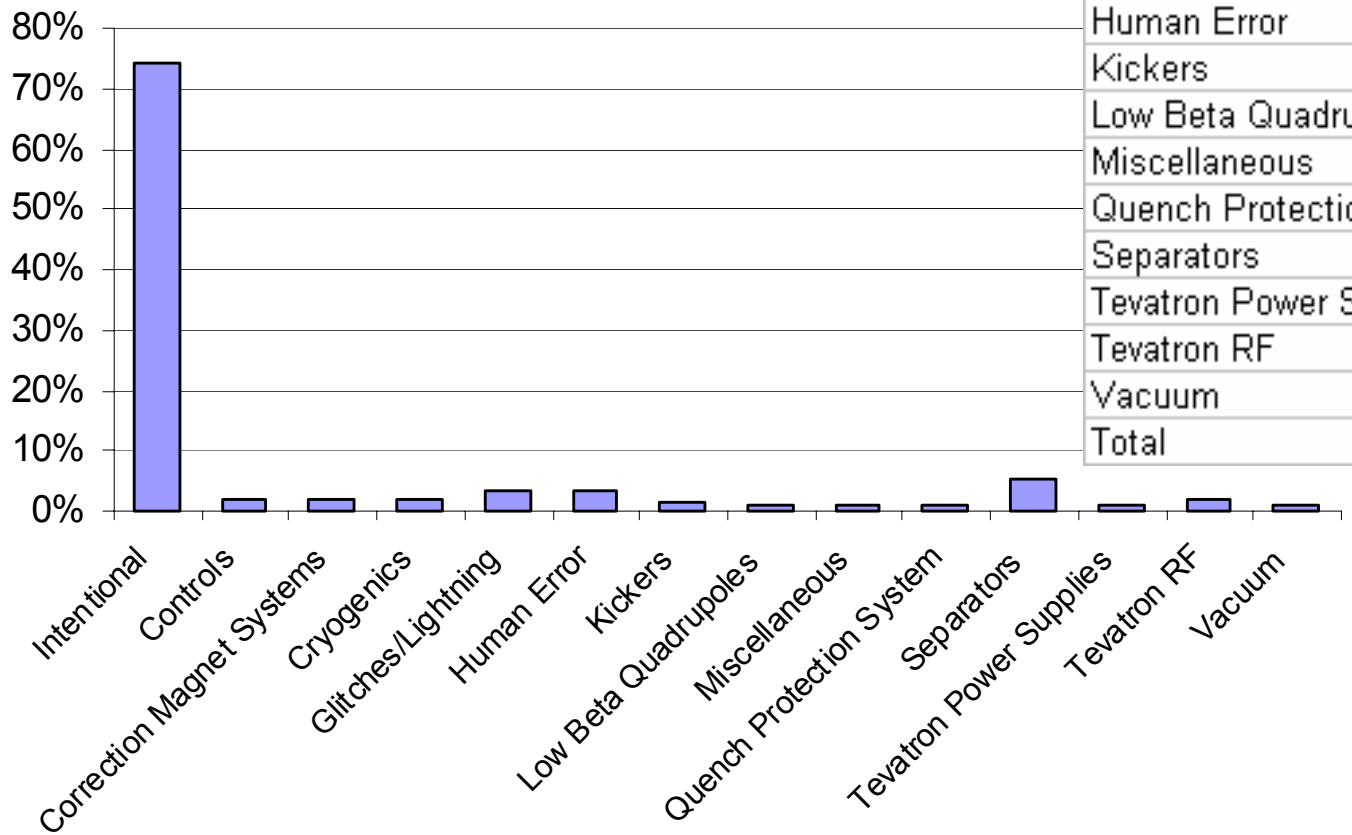
- 2 low lumi stores requested for CDF & D0 diffractive physics programs (forward pots)
- Low intensity 36x36, 28 cm β*: $L = 0.7\ (10)^{30}\ cm^{-2}\ s^{-1}$
- Normal intensity 1x1, 1.6 m β*: $L = 0.5\ (10)^{30}\ cm^{-2}\ s^{-1}$

- Completed successfully
  - Diffractive physics program effectively complete
  - CDF removed pots to install longer collimator @ A48

Reliability by Week in 2005+2006



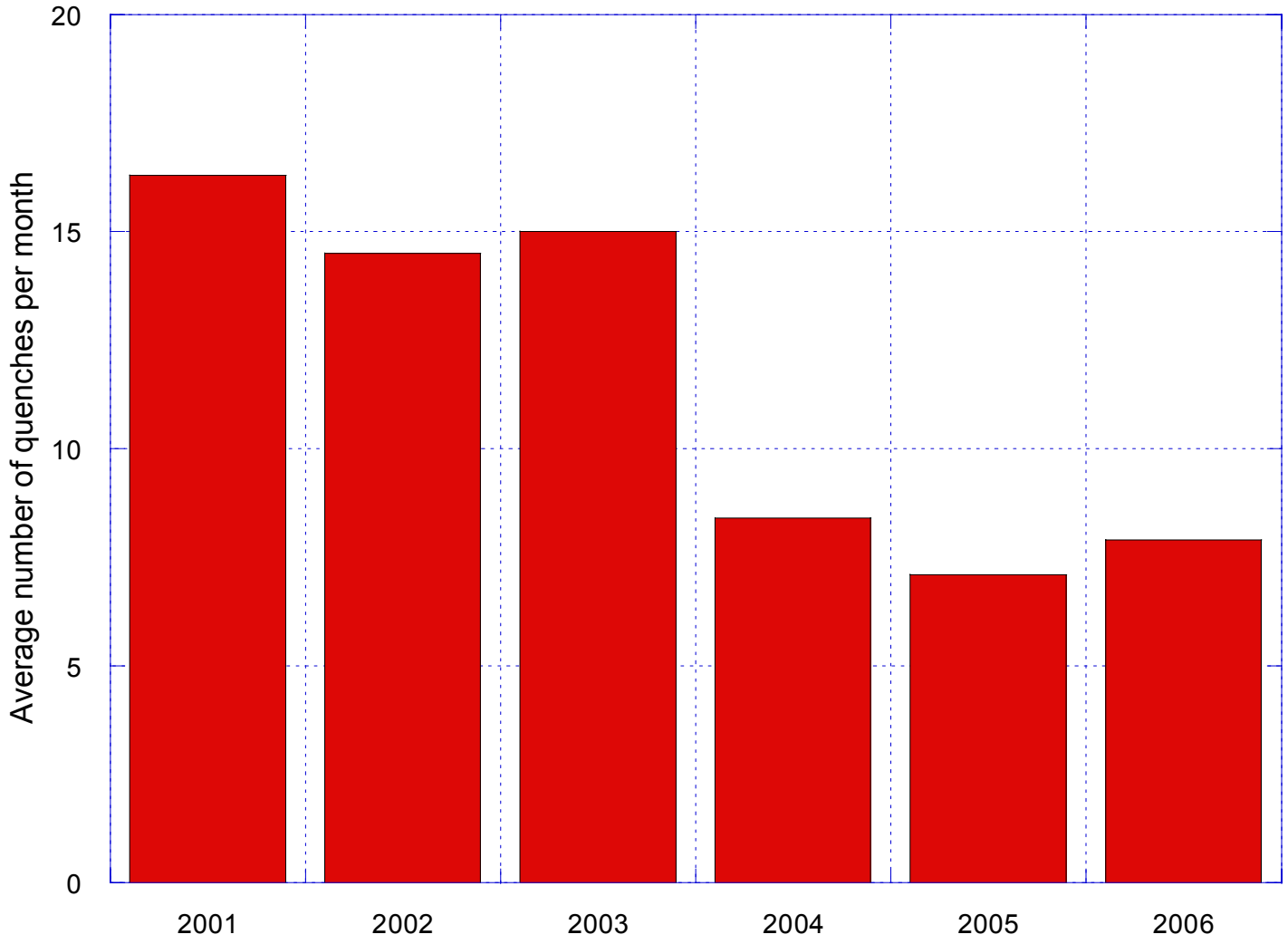
Store Termination by Category



Intentional	74%
Controls	2%
Correction Magnet Systems	2%
Cryogenics	2%
Glitches/Lightning	3%
Human Error	3%
Kickers	1%
Low Beta Quadrupoles	1%
Miscellaneous	1%
Quench Protection System	1%
Separators	5%
Tevatron Power Supplies	1%
Tevatron RF	2%
Vacuum	1%
Total	100%

from J. Crawford's Operations spreadsheet

Tevatron Quenches/Month



Component Failures

- Nov 21 – B17 spool package
  - B11 horz separator spark caused multi-house quench
  - Kautzky valve on spool failed closed

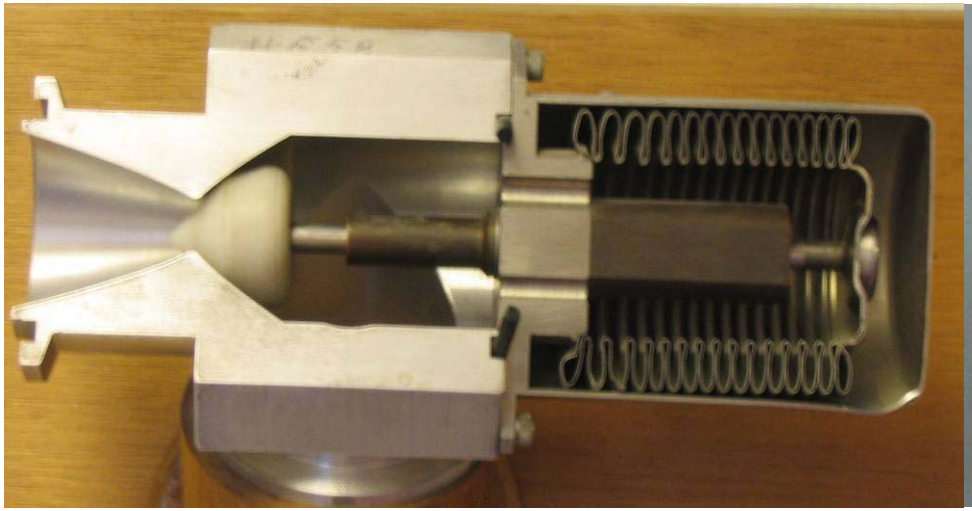
- Jan 24 – Insulating vacuum leak in A44
  - Operator error – left SQD0 (skew coupling) supply off
  - Tunes landed badly after initiating collisions, large losses
  - A44 cell not hit with losses, quenched with adjacent cells
  - Faulty O-ring installation years ago finally failed

- Feb 22 – F47-2 dipole
  - Spare abort input pulled abort spuriously
  - Kautzky valve on dipole failed closed

Kautzky Valve Poppets

- During quench, pressure forces valve open, allows He to escape
- Poppet can break off, remain in closed position
- 1 similar failure in 20 years, now 2 in three months
  - Replace all ≈1200 He Kautzky valve poppets during shutdown

Closed Kautzky valve



Broken poppet from B17 spool Kautzky valve

Aborting Beam More Quickly

- Quench Protection Monitor (QPM)
  - Prior to Dec 03, ran on 60 Hz clock (16.7 ms)
    - Beam could circulate 100s of turns after quench
  - Modified in 2004 to "fast-abort" within 900 μs of quench
  - Tweaked after Nov 21 quench to pull abort within 550 μs
- Voltage-to-Frequency Converters (VFC)
  - Testing modification to speed measurement of resistive voltage across magnet cell
- New Beam Loss Monitor (BLM) Electronics
  - Will allow improved performance, greater flexibility
  - Being installed during shutdown

Machine Studies and Maintenance

- Refer to Study Document (Scorecard response)

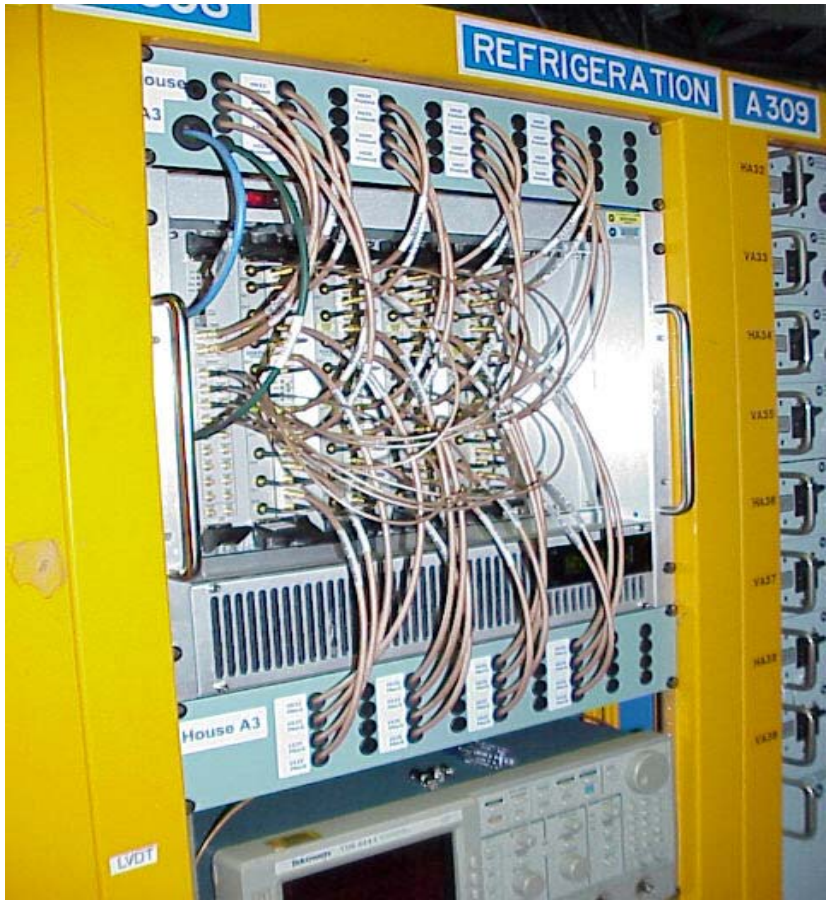
- Averaged ≈10 hrs / week since last shutdown
- Exploit natural breaks in machine operation
  - Lost stores, pbar stacks, etc.
- Exploit end-of-store studies
- Focus on specific, well-prepared studies
  - Be efficient, prevent unnecessary quenches/downtime
  - Start with proton-only stores before trying in HEP
- If we really need study time to implement something new for HEP, will get the time

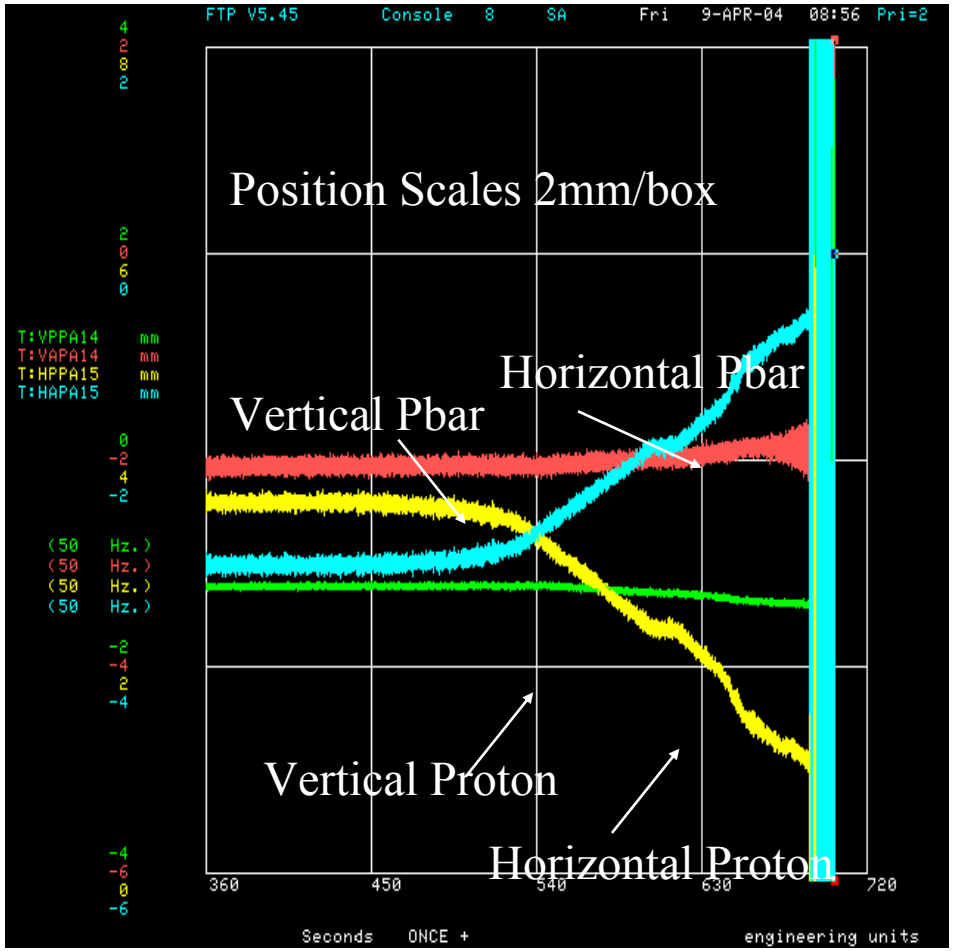
Instrumentation

Upgraded BPM Electronics

- Installed house-by-house over few months
  - In study periods, between HEP stores
- An order of magnitude improvement in proton position measurements and new for pbars
  - Position resolutions in the range of ~10-25 μm
- Exploiting improved resolution and reliability
  - Lattice measurements
    - Identified rolled quads (incorrectly fiducialized at magnet factory)
    - 28 cm β* + optics correction
  - Orbit motion
  - TBT coupling measurement/correction during shot-setup

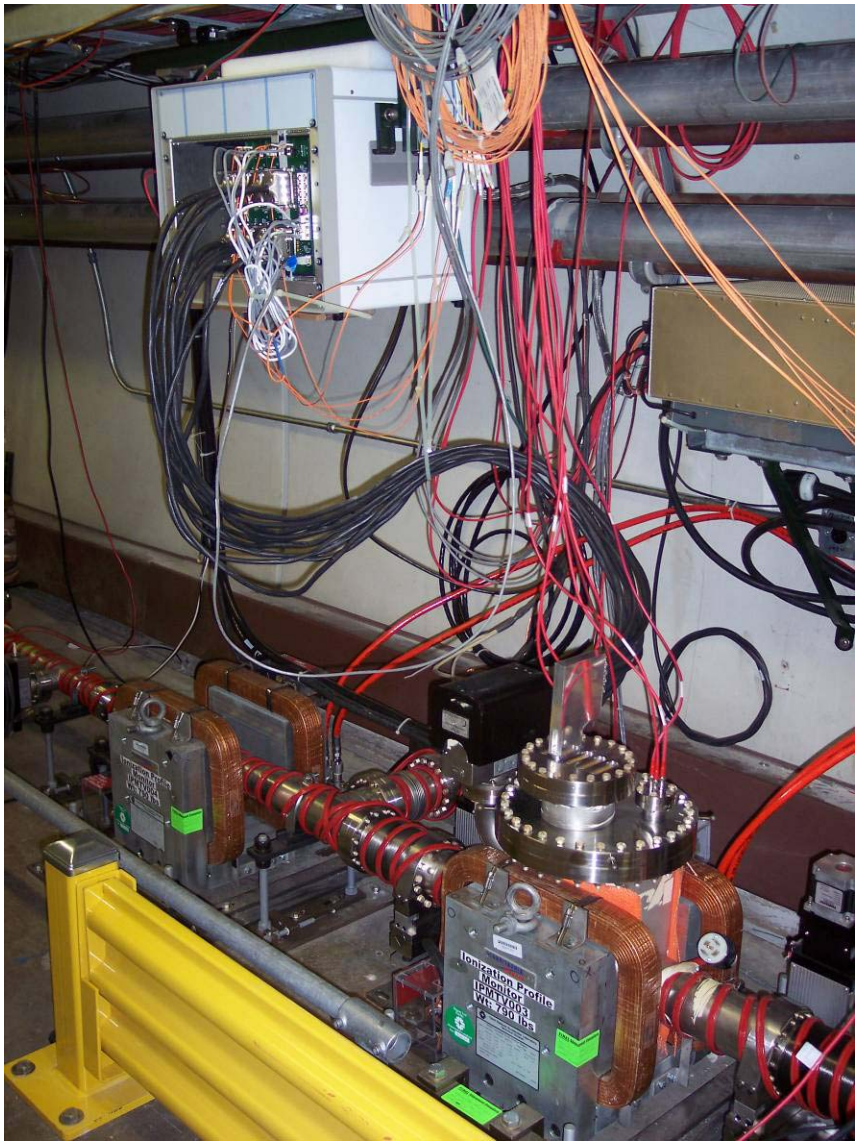
Upgraded BPM Electronics



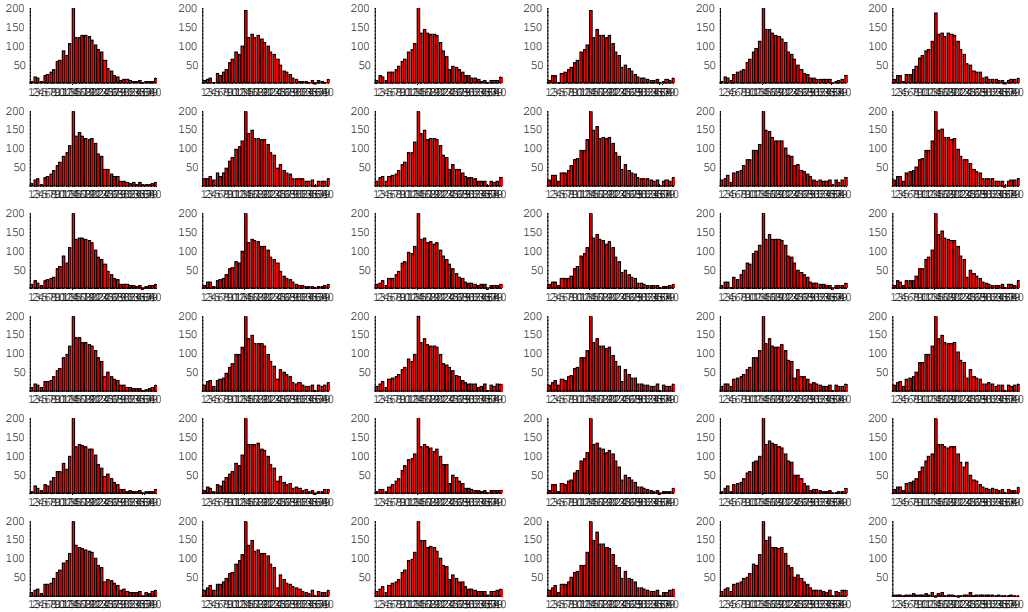


Ionization Profile Monitor (IPM)

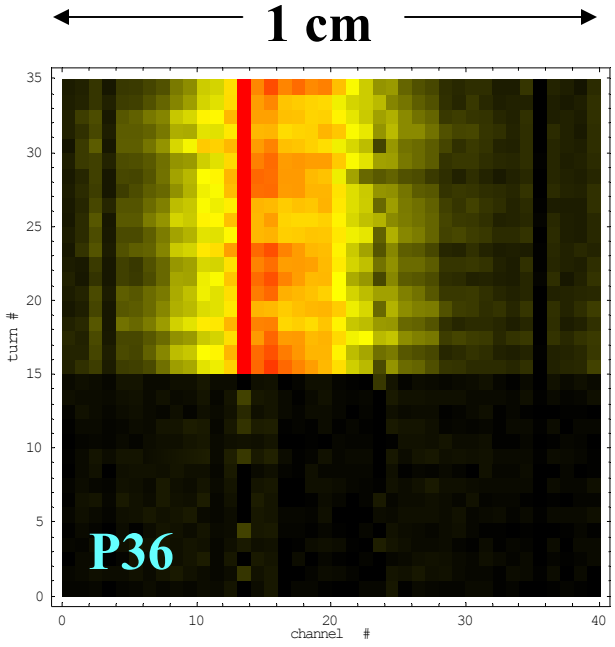
- Installed one detector and partial readout system in Dec 05
- Some problems found and fixed
  - Poor vacuum
  - Ground noise
  - High voltage arcing
  - Trigger and data synchronization
- Recorded first data
- Complete detector installation with full readout during ongoing shutdown



IPM Data – Store #4642



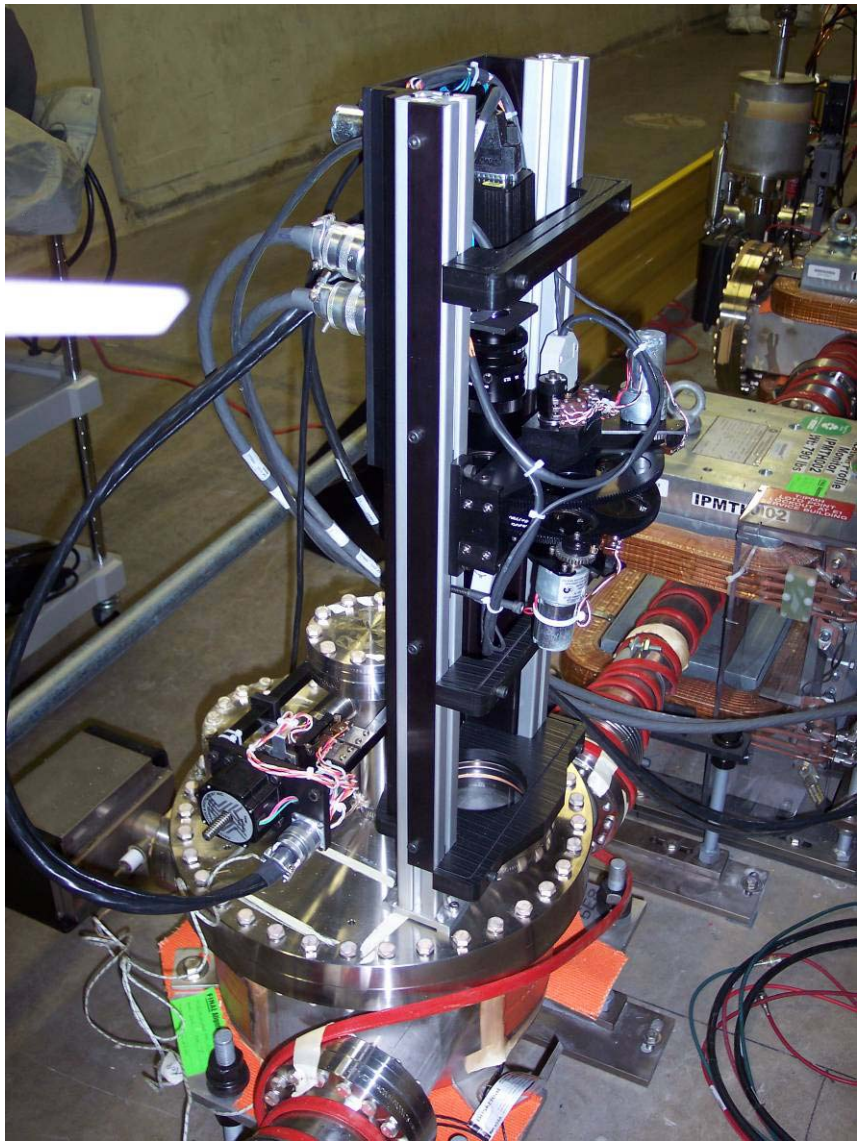
Single-turn proton bunch profiles 16 turns before injecting P36



A. Jansson

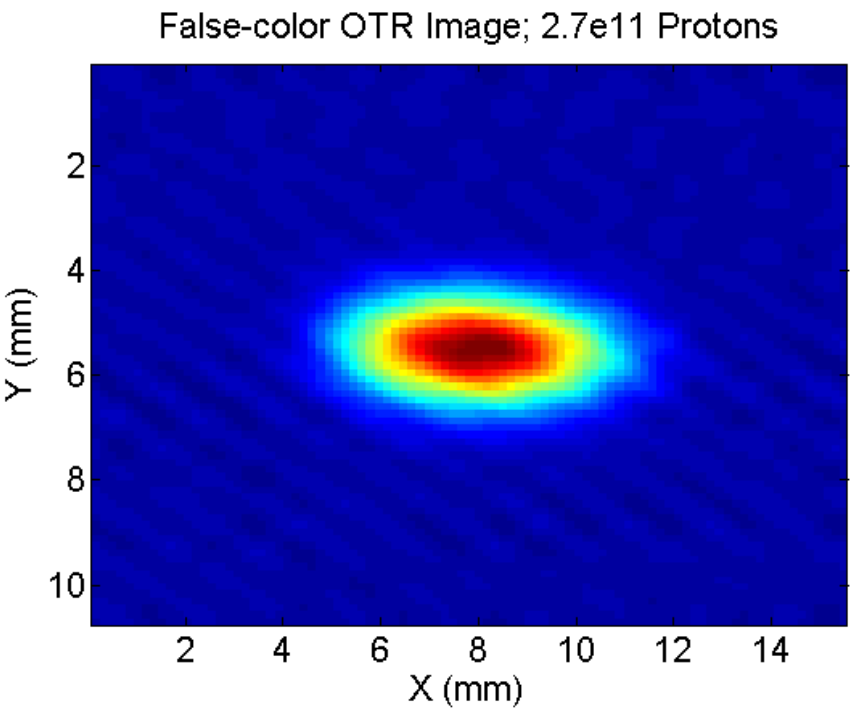
Optical Transition Radiation Detector (OTR)

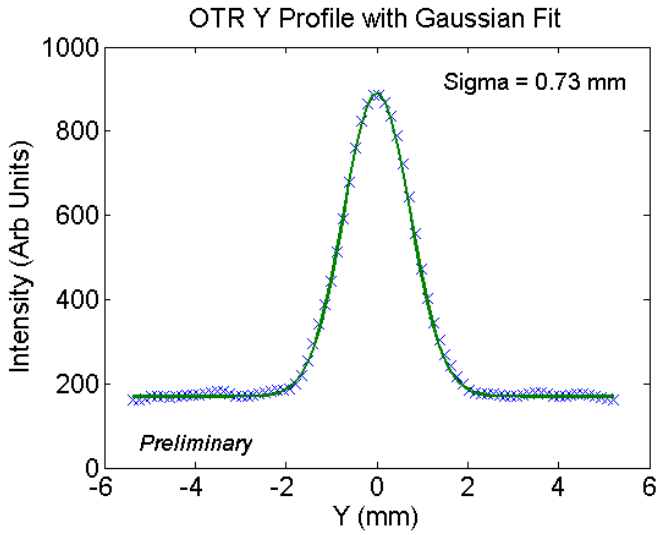
- Rad-hard camera images OTR
  - Proton and pbar imaging
- Installed at E0 near IPM
- Used for single → few turn injection studies
- 5 μm aluminized mylar foils
- Unique 2-D beam profile detector
  - Others only 1-D
- High resolution
  - 130μ x 170μ size pixels
- Installed in December 2005

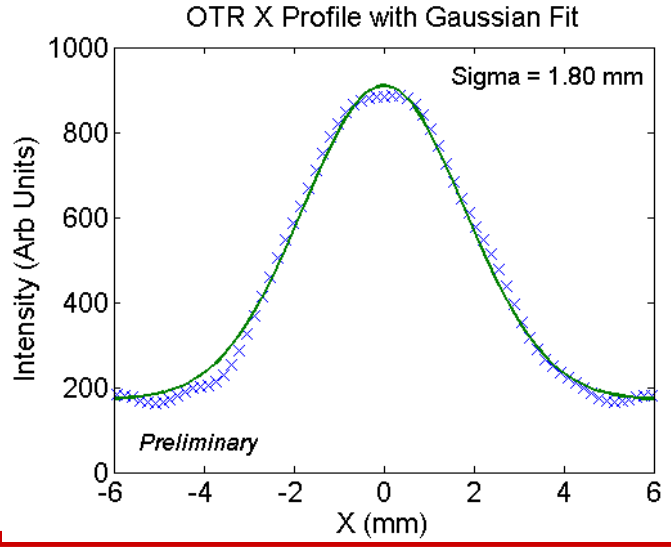


First Results from Tevatron OTR

Single turn measurement of
single coalesced proton bunch

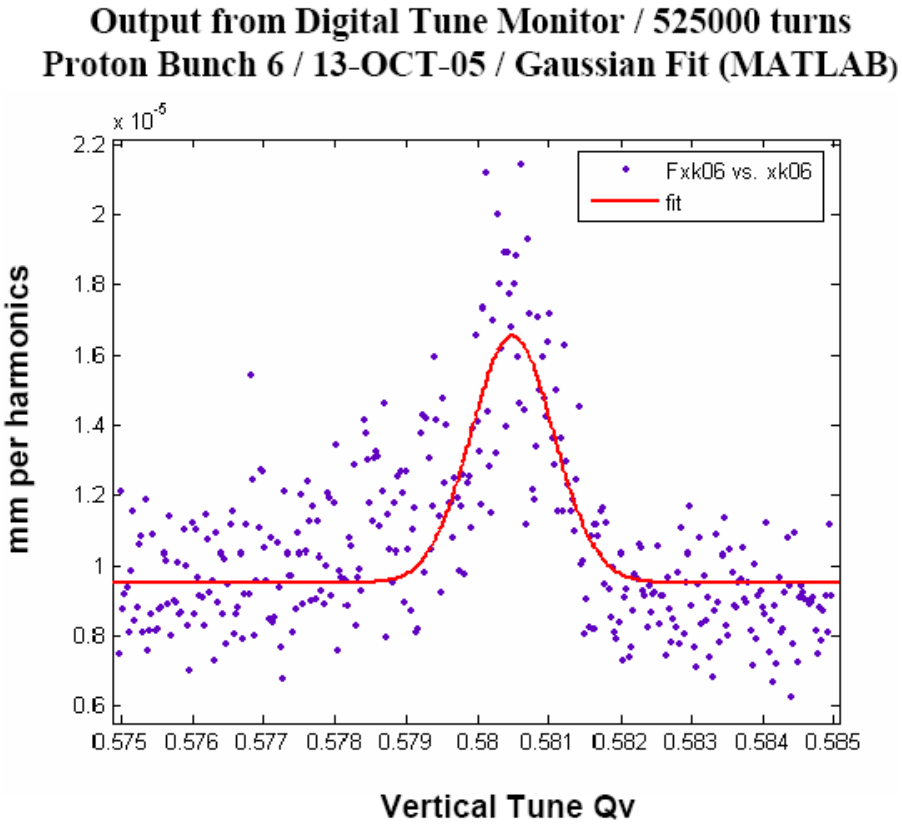


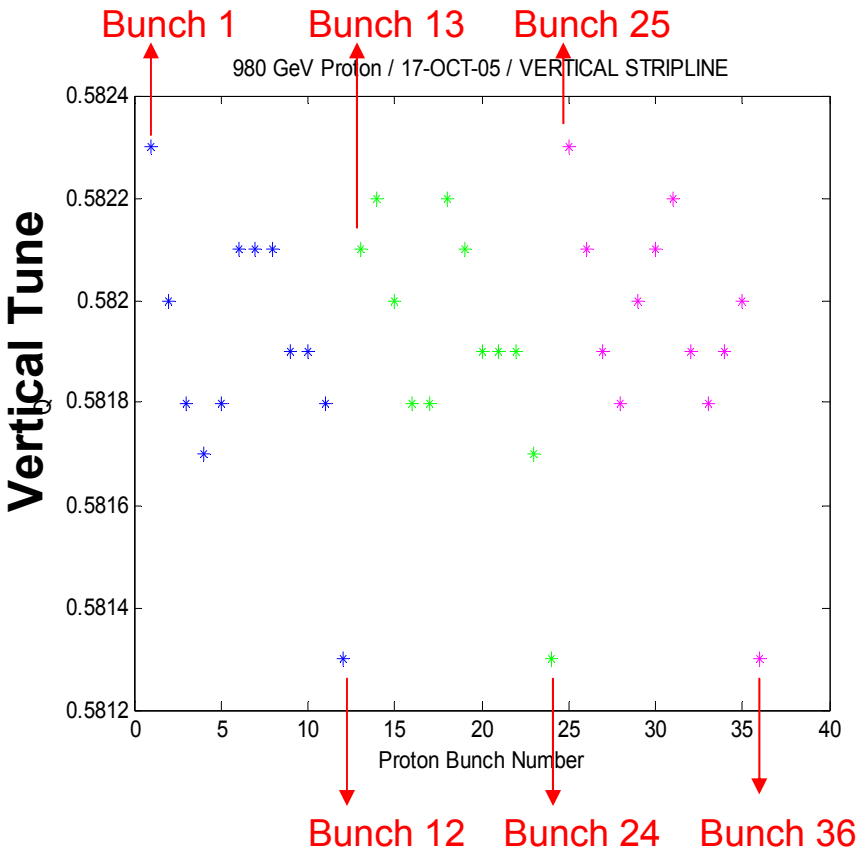




V. Scarpine

Early Measurements from New Digital Tune Monitor

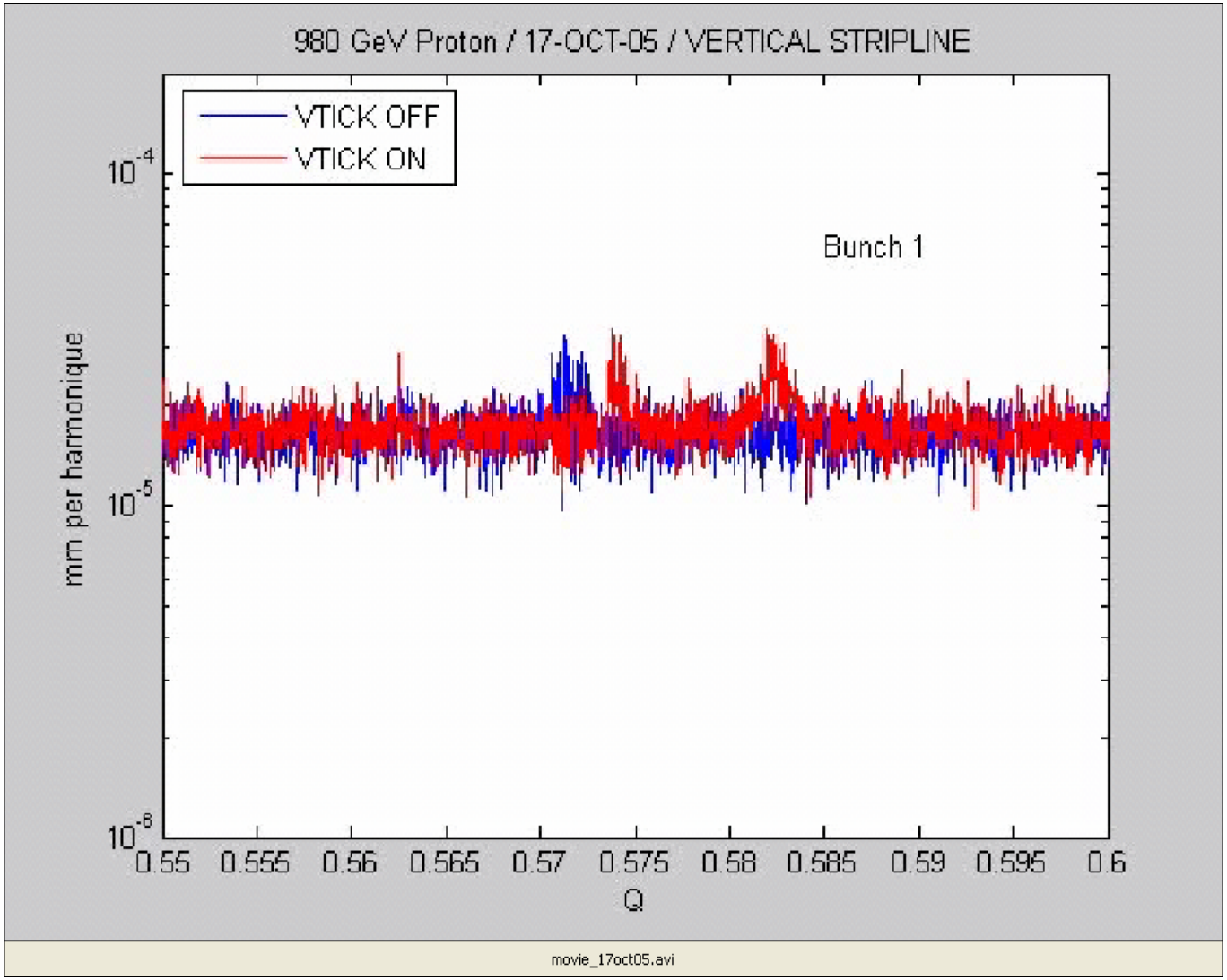




- Uses stripline as pick-up, FFT on TBT data
- Hope to use without external excitation
- Taken some data, 100 MHz 16-bit ADC still being improved
- Continue development after the shutdown

Proton Bunch Tunes from Digital Tune Monitor

This video clip shows bunch-by-bunch oscillation differences among protons during HEP with (red) and without (blue) excitation.

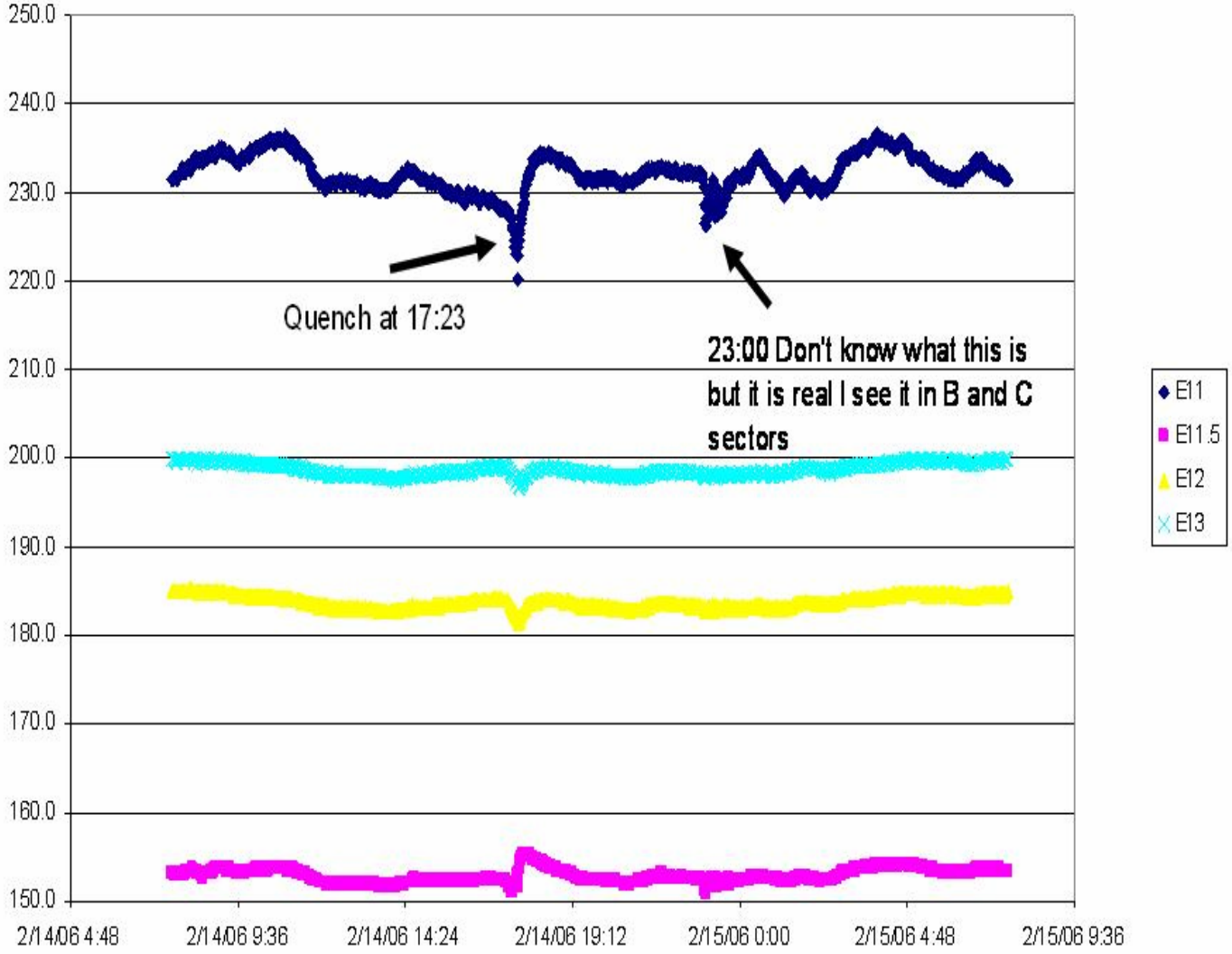


Magnet Motion

- How do see magnet motion?
  - Tiltmeters, LVDTs, water levels, surveys
- Observed magnet motion on different time scales
  - Slow drift over weeks, months
    - Ground motion, etc.
  - Wiggles, jumps over seconds, minutes, hours
    - Quenches, earthquakes, HVAC, weather, tides
  - Vibrations at few → tens of Hz
    - Traffic, pumps
- ~μm magnet motion near IPs give ~mm orbit changes in arcs
  - Readily observable during stores using BPMs

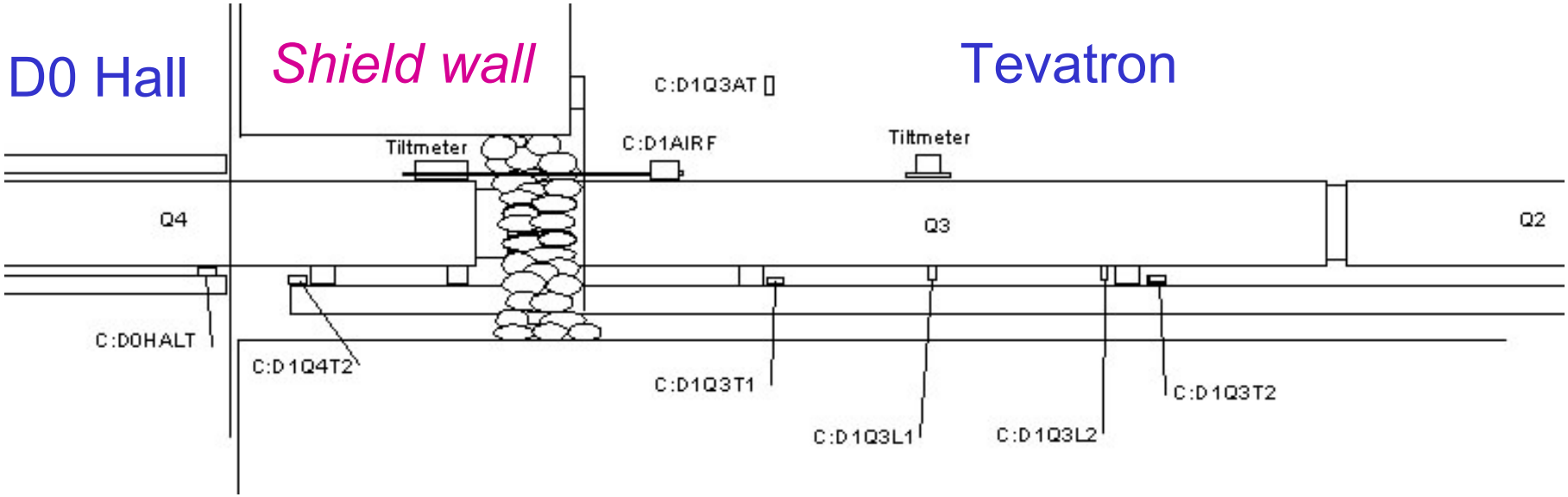
Water Levels See Quench

J. Volk

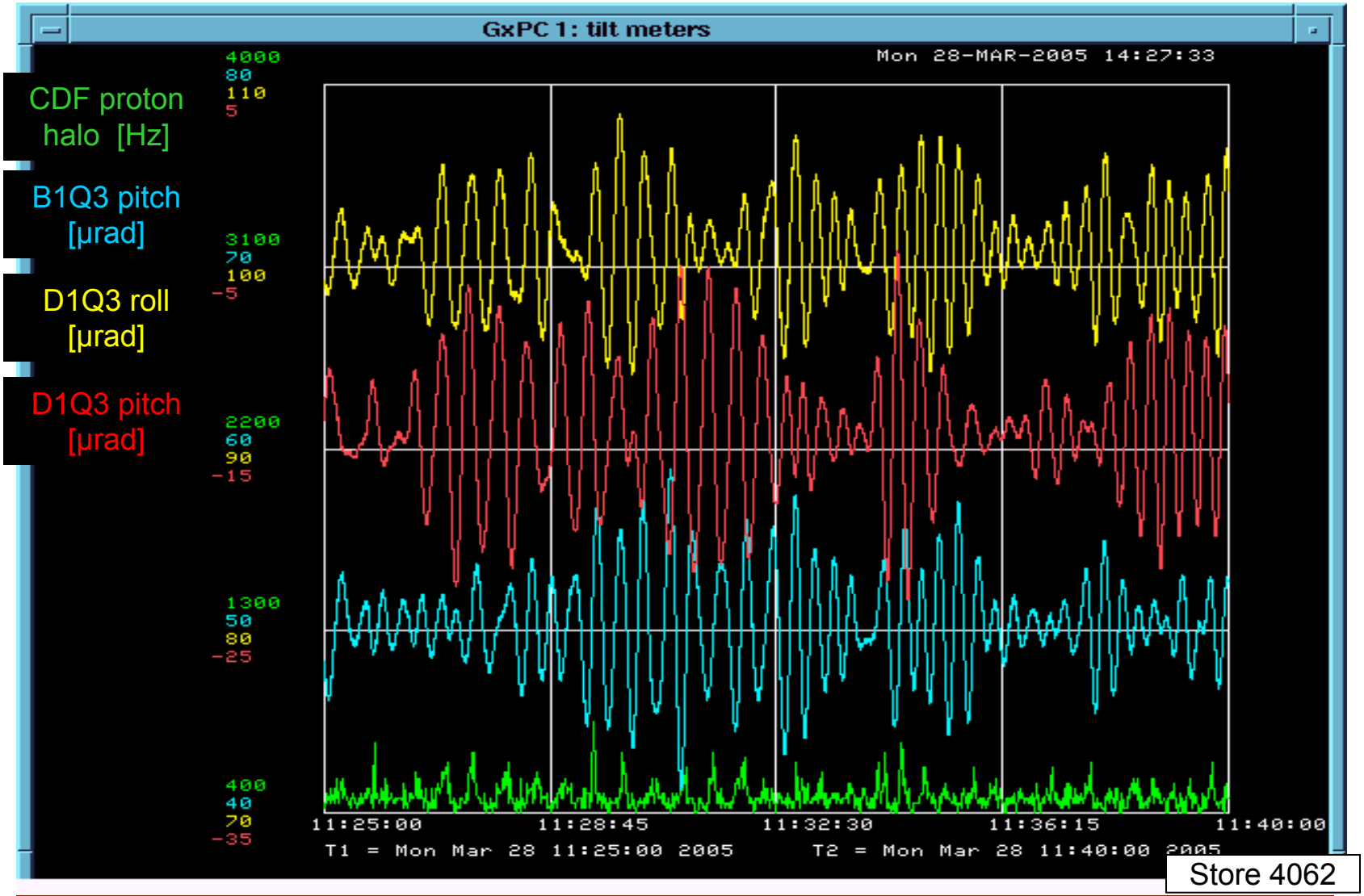


Sensors on Low-Beta Quads

- Lots of instrumentation on low-beta quads, girders to investigate motion
  - LVDTs, tiltmeters, temperature, air flow
- Understand more about magnet motion and weather conditions in and out of the collision halls



Sumatra Earthquake 3/28/05

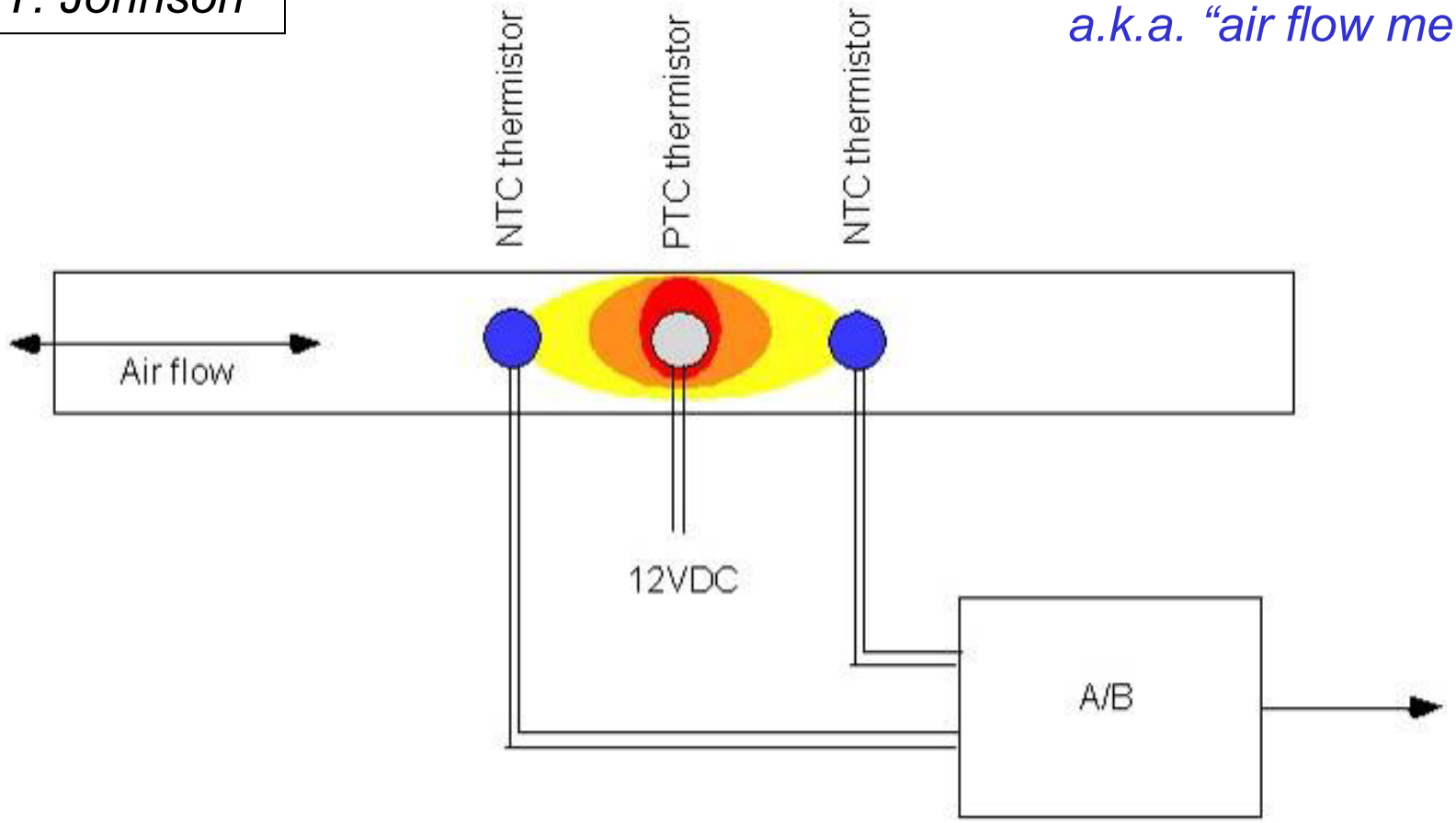


Store 4062

Differential Thermoanemometer

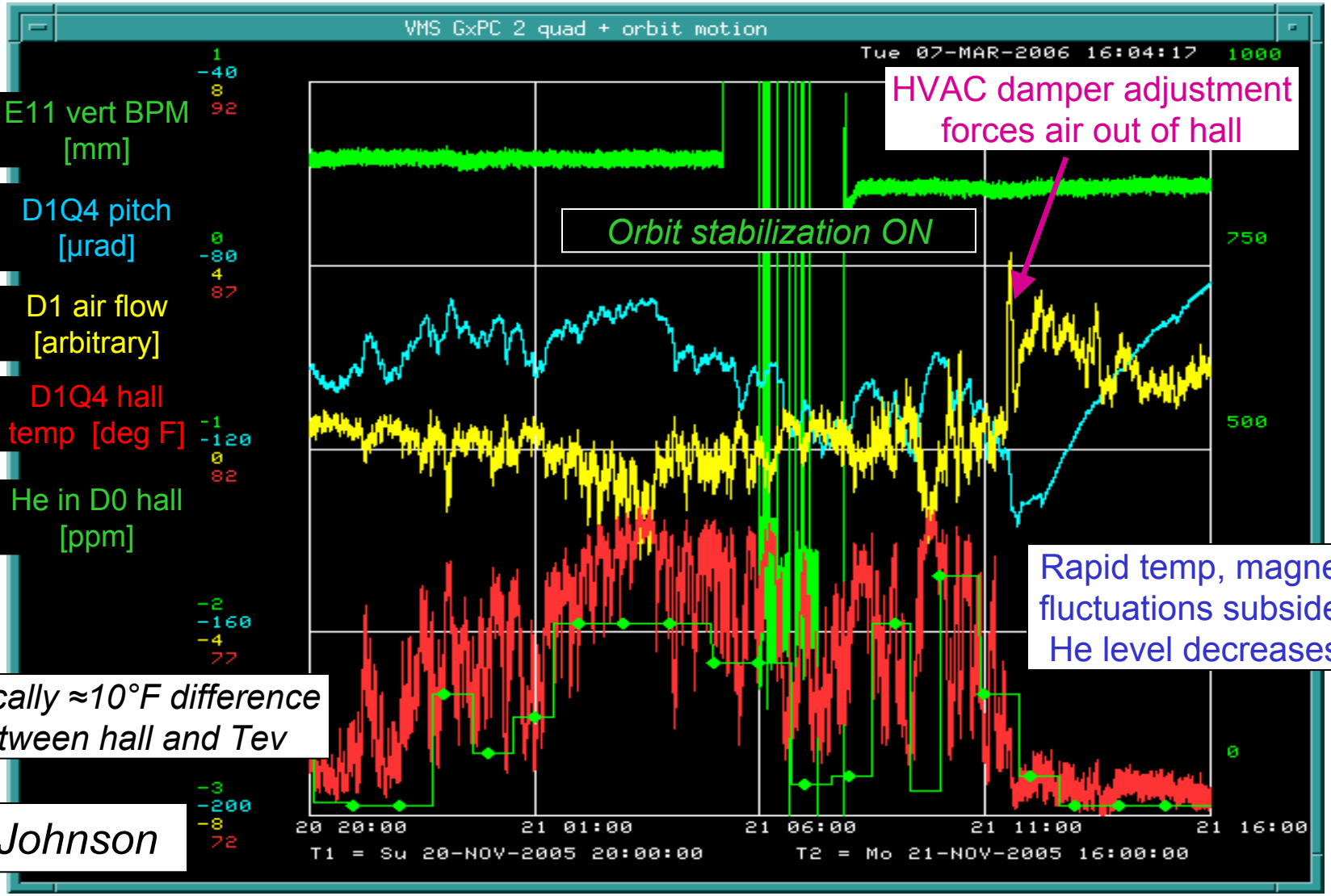
T. Johnson

a.k.a. "air flow meter"



PTC thermistor operates in "self heat" mode, maintaining a temperature of 80C. Air movement imbalances the heating of the two NTC thermistors, giving a direction and relative velocity.

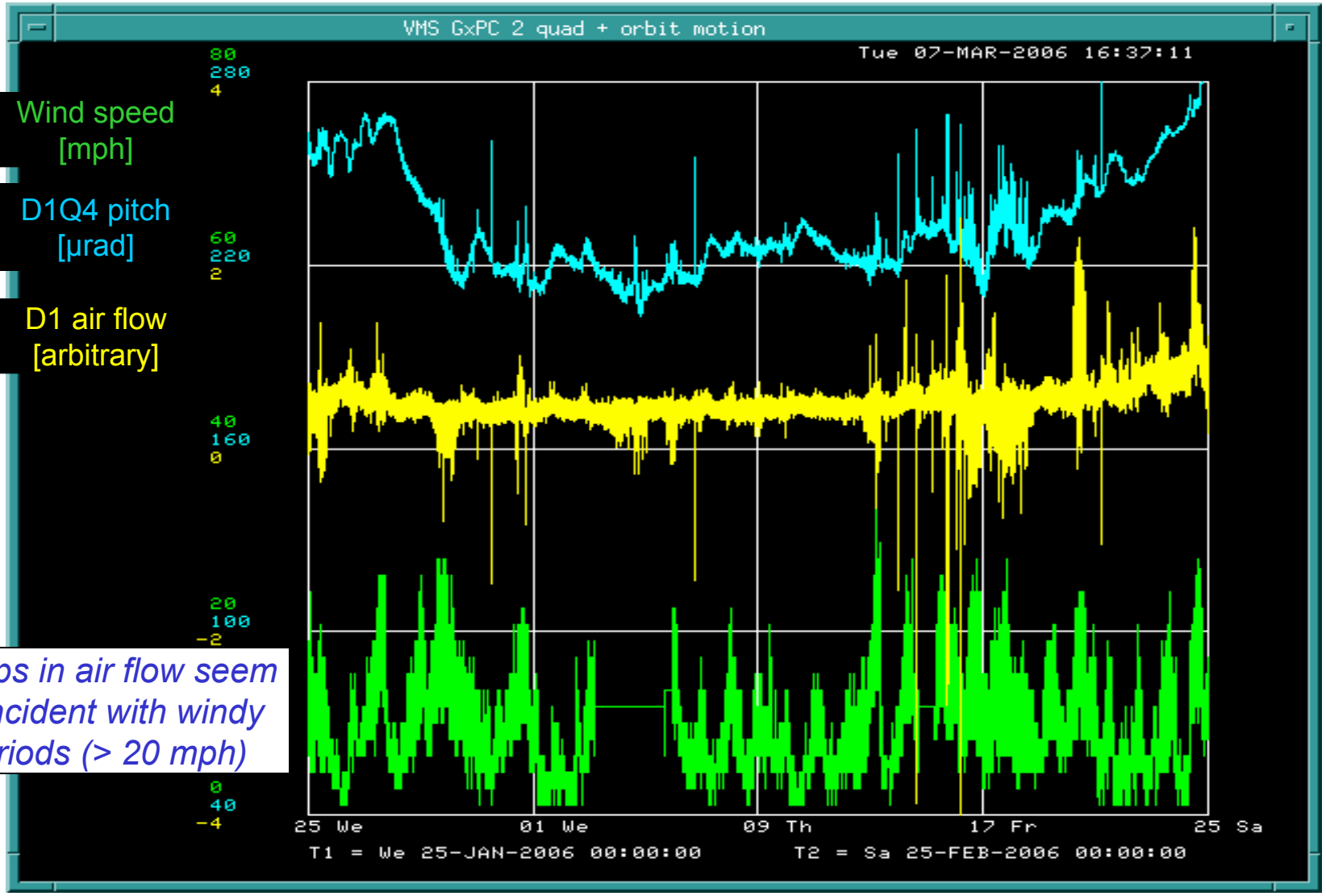
Quad Motion Depends on Hall / Tevatron Differential Pressure



Typically ≈10°F difference between hall and Tev

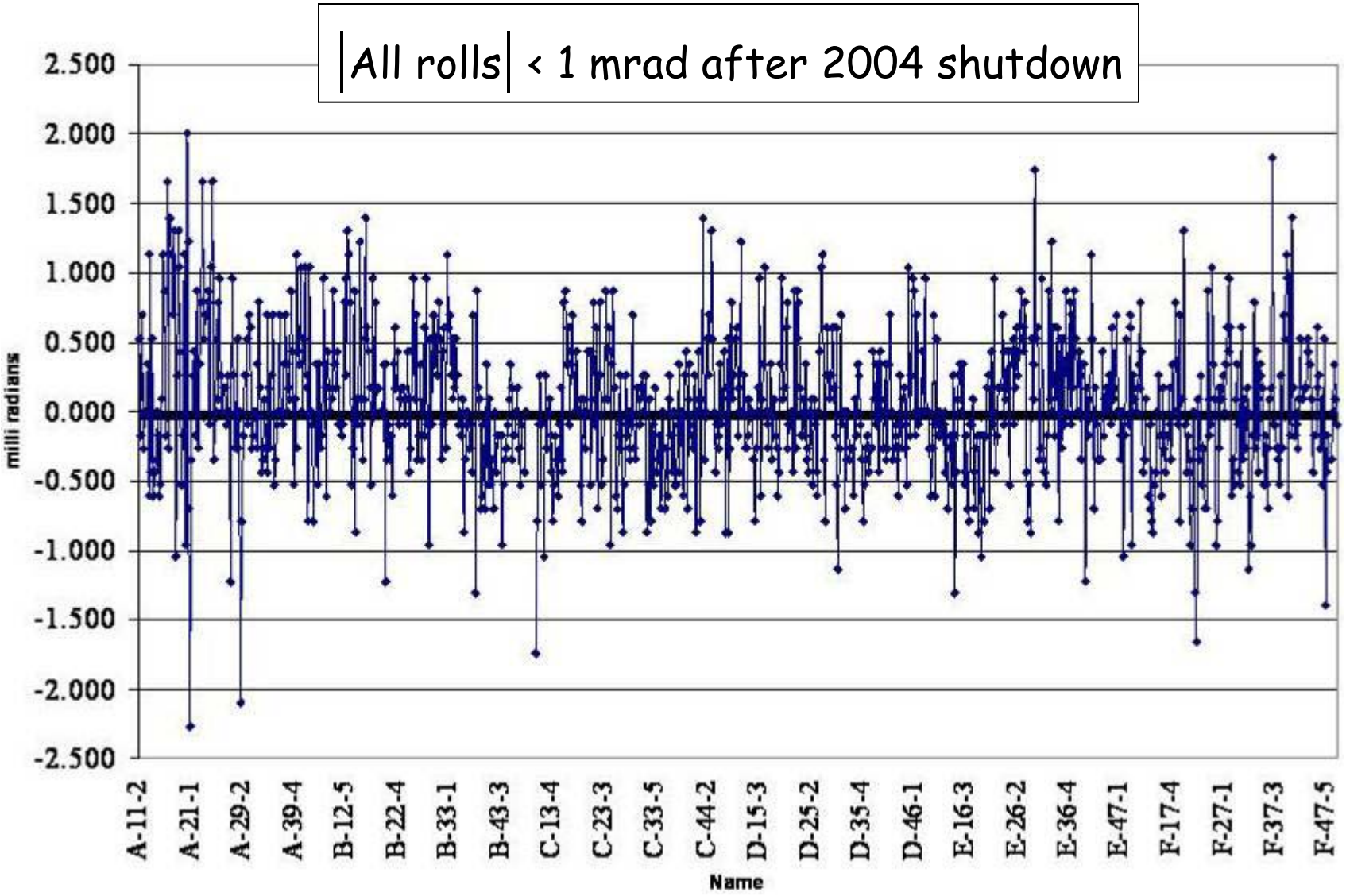
T. Johnson

Correlations with Weather



Jumps in air flow seem coincident with windy periods (> 20 mph)

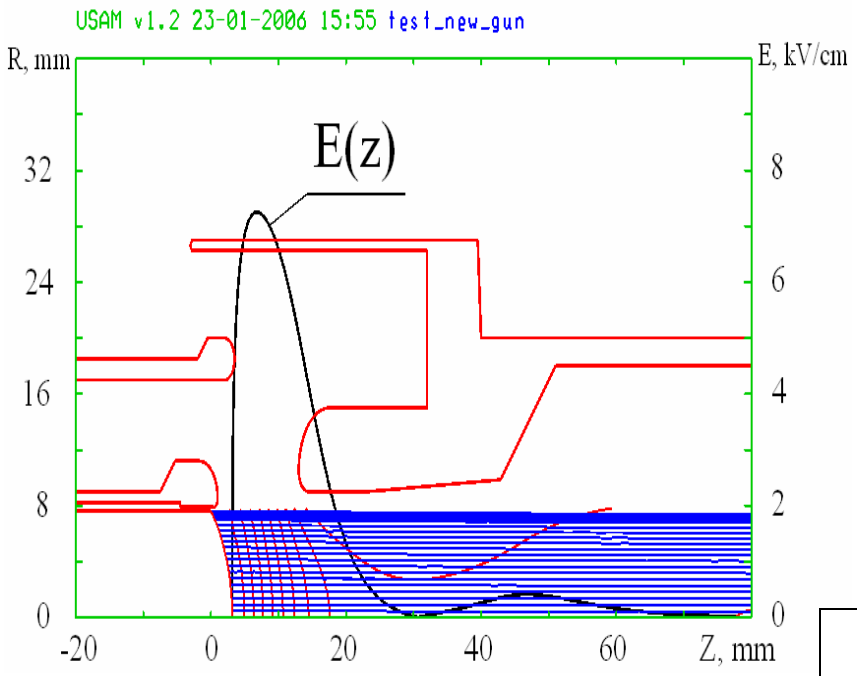
Tevatron Magnet Rolls (March 2006)

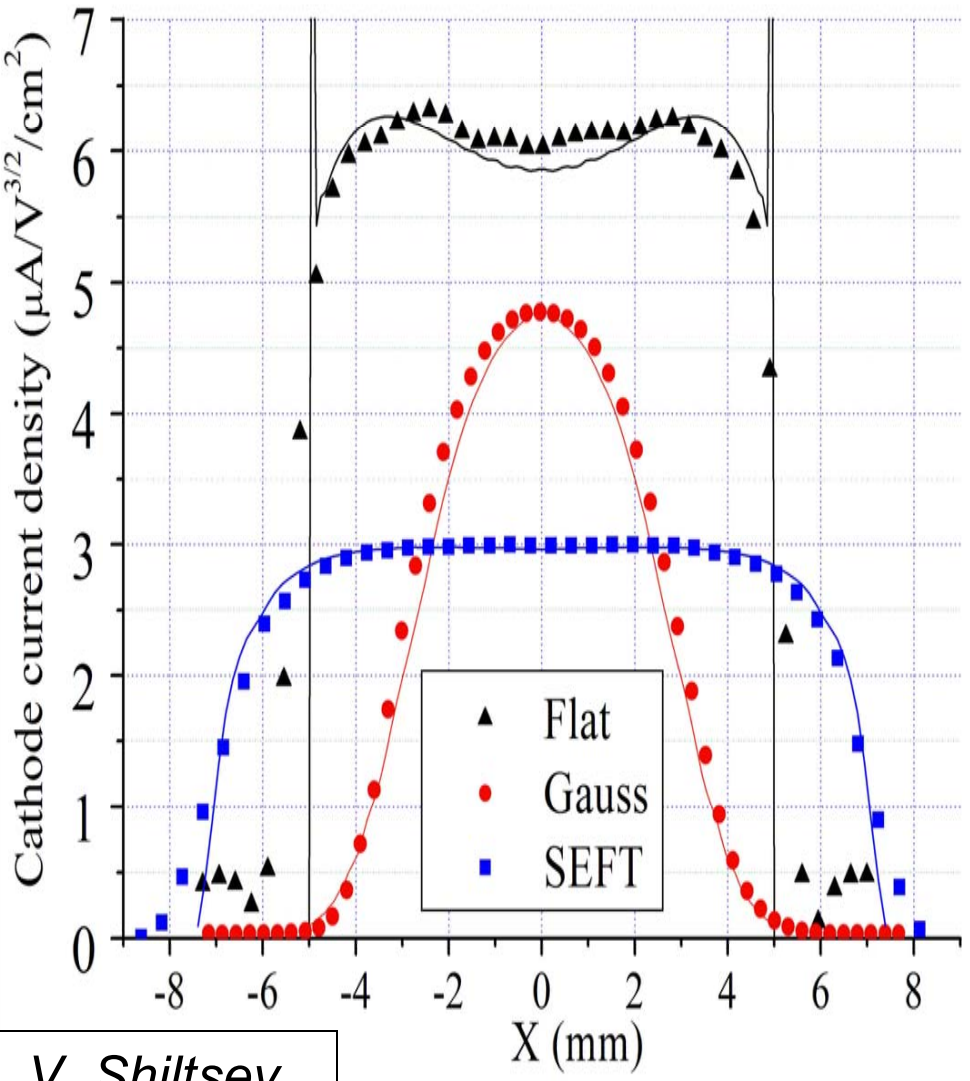


TEL Progress

New SEFT Gun

- Beam studies in 2003-05 → need smoother edges, Gaussian too narrow → SEFT gun
- Simulated (below), designed, built and tested in 2005
- Installed in TEL-1 on 12/08/05

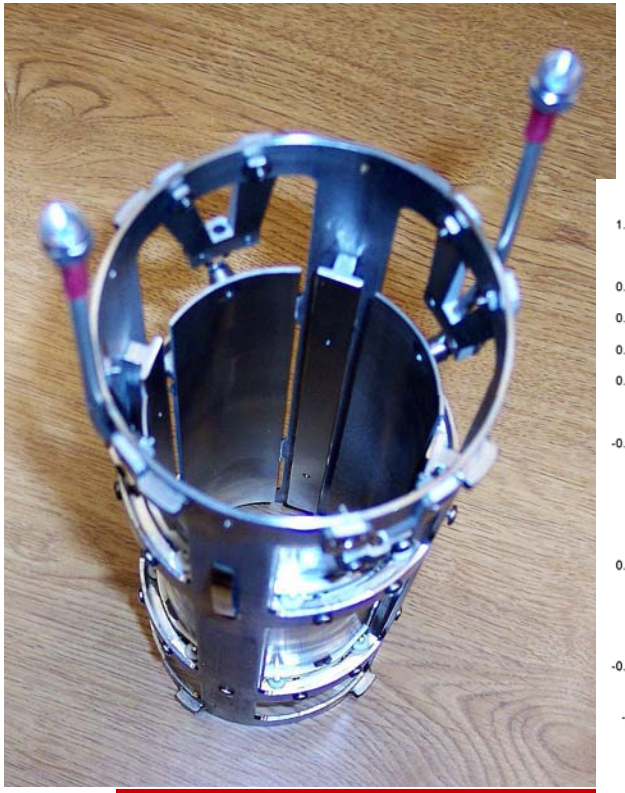


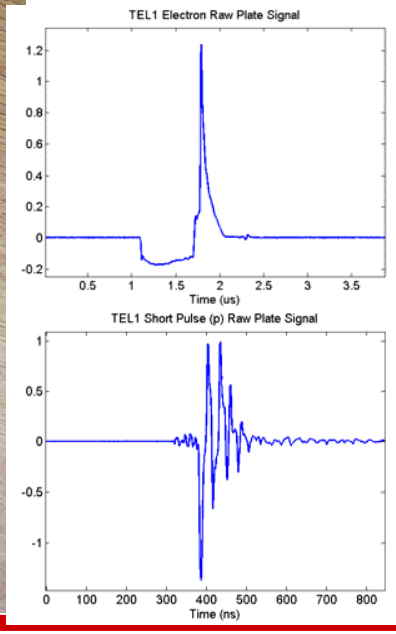


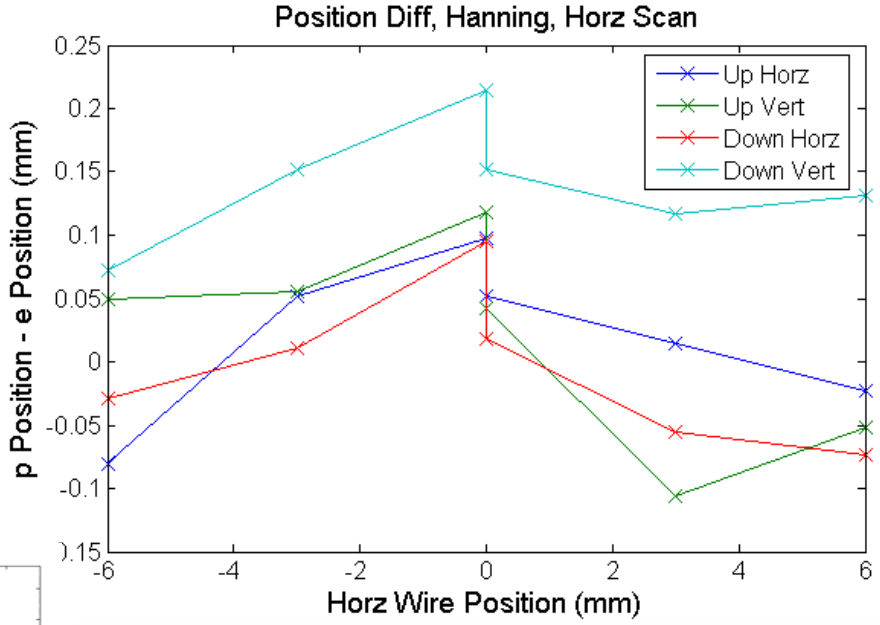
V. Shiltsev

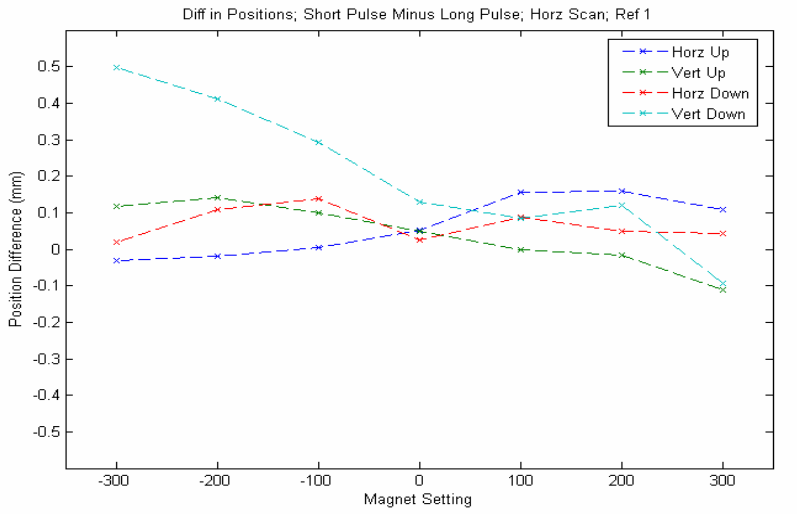
TEL BPMs Improved

- TEL-1 BPMs have position difference ~1 mm btw p's and e's
- New BPMs designed and built for TEL-2 + narrow band algorithm reduce error to ~0.2 mm



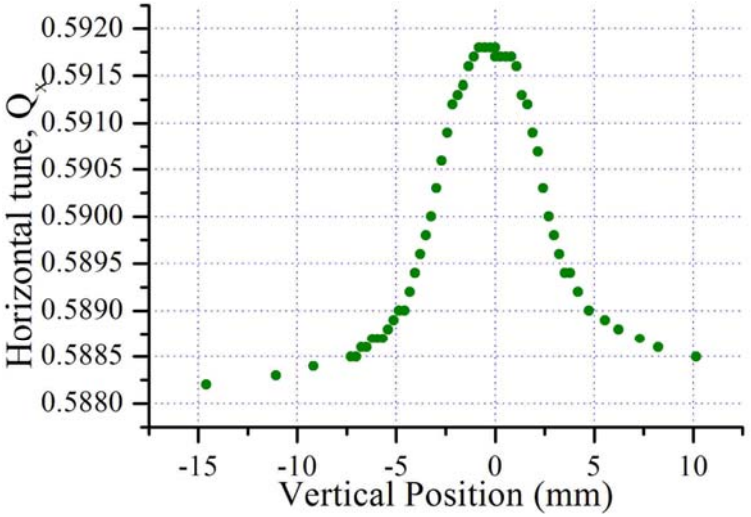


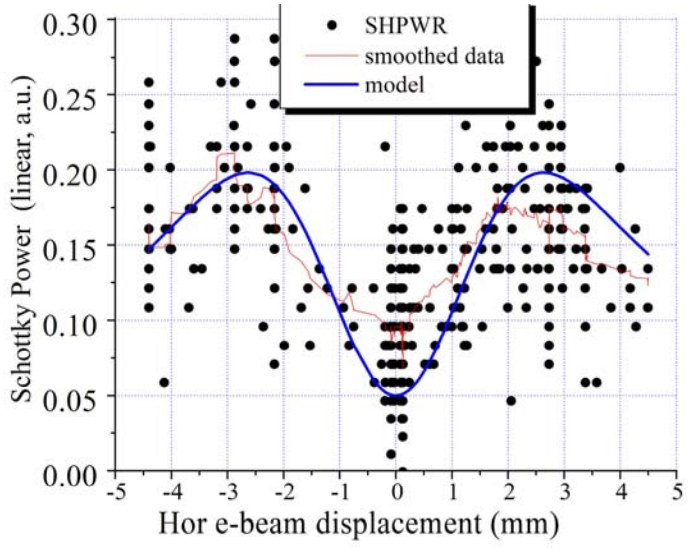


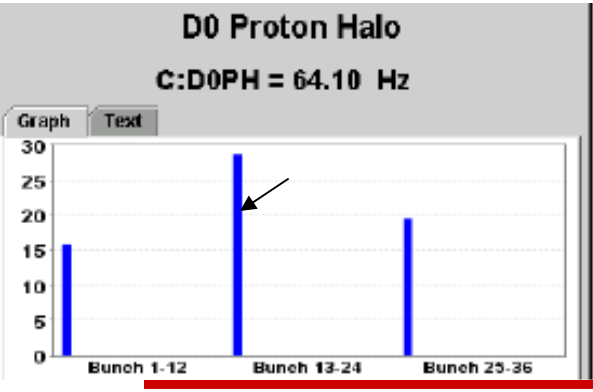


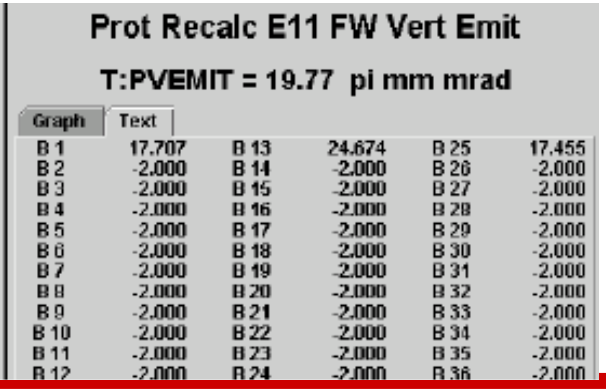
TEL-1 BBC studies in 2005-2006

- Over two years '04-'06:
  - 6 studies=20.5 hrs
- Major results:
  - Lifetime vs dX, Q_x,y with Gaussian gun
  - Tune spread due to Gaussian gun (did not detect)
  - dQ=0.004 SEFT gun, easy centering
  - Great lifetime 130-340 hrs with SEFT gun
  - Simultaneous abort gap cleaning and beam-beam compensation possible



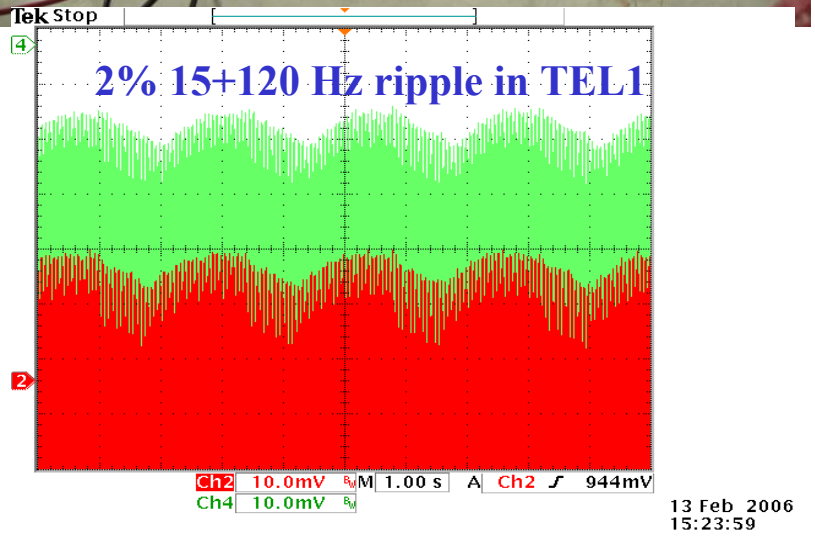






Current activities/issues

- TEL-1
  - PSs, HV PSs, modulator problems
    - Ripple ~2% in HV amplitude
  - SEFT gun died after Feb 24 quench
  - He-vacuum leak developed in TEL-1 after same quench,, under repair
- TEL-2 tested, being installed in A0
- New MARX HV generator developed but not tested yet
- Comprehensive program of parallel LIFETRAC simulations to be started (BBC in Tev, RHIC and LHC).



Separator Progress

Table of Separator Stations

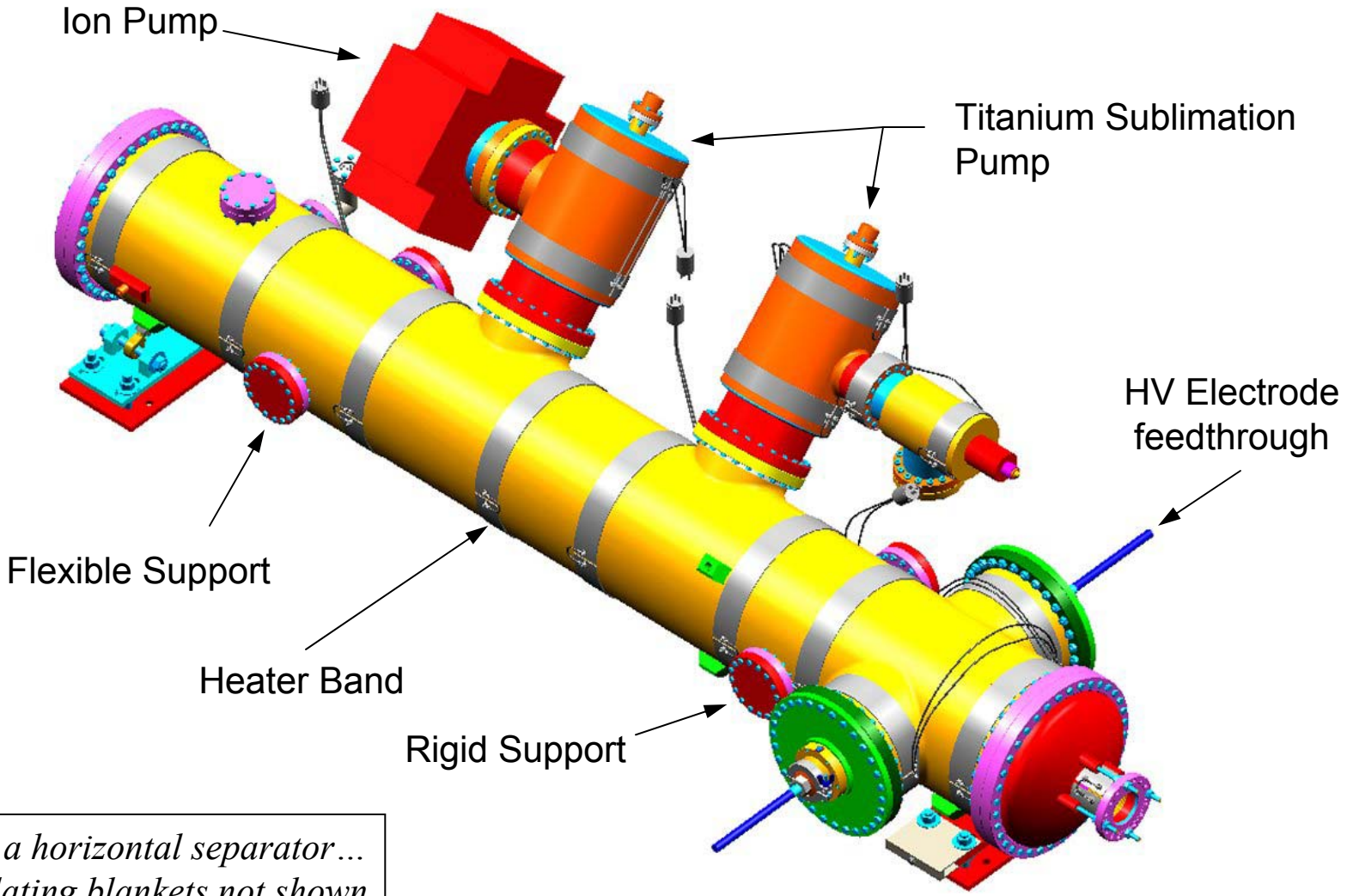
Horizontal	# modules		Vertical	# modules
B11	2	short arc	B11	1
B17	4		B48	1
			C17	4
C49	1		C49	2
D11	2	long arc	D11	1
D48	1		D17	2
A17	1		A17	1
A49	1		A49	2

New separators being installed in the current shutdown

Total: 26 separator modules + 4 spares

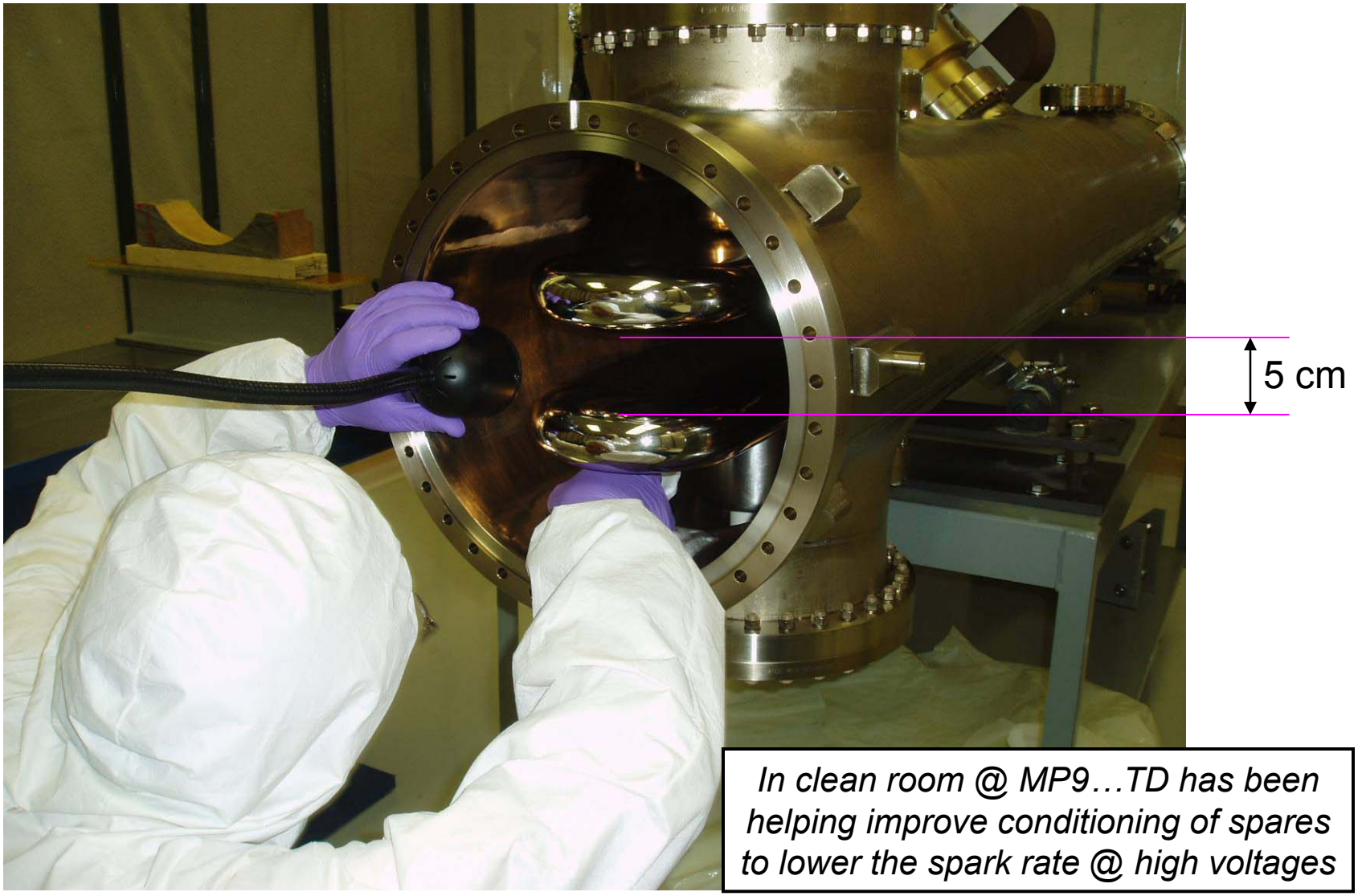
Each station has 2 power supplies, polarity switch, resistors, controls…

Tevatron Electrostatic Separator Components



This is a horizontal separator…
…insulating blankets not shown

Looking into a separator

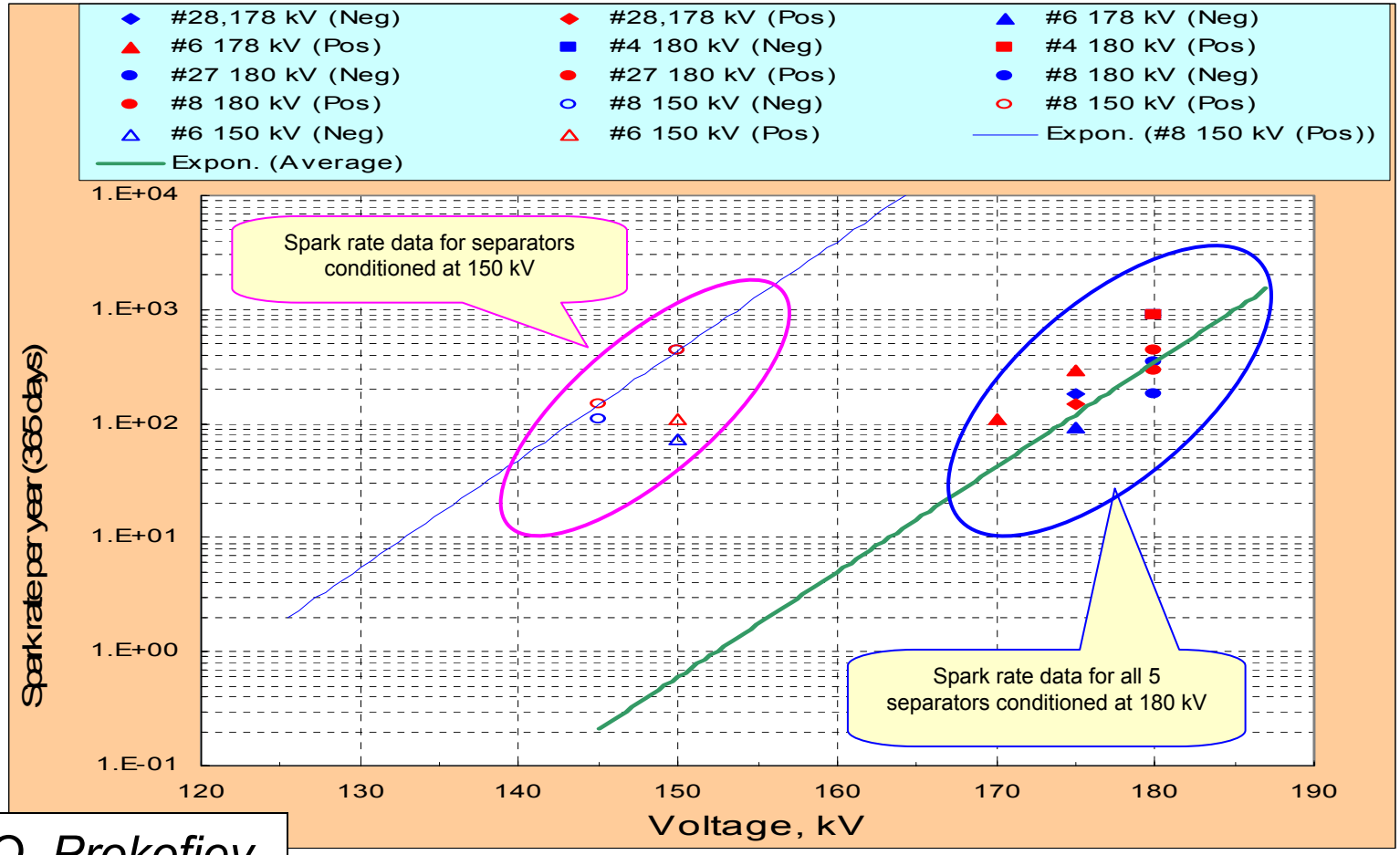


In clean room @ MP9…TD has been helping improve conditioning of spares to lower the spark rate @ high voltages

Separator Progress (with TD)

- Conditioned 5 spares up to ±180 kV (72 kV/cm)
  - Achieved 1-2 sparks/day
  - Previous specs were 1 spark/day @ 150 kV
- Comparing electropolished vs hand-polished stainless steel electrodes
  - 3 separators have electropolished electrodes
  - Electropolished show similar spark rate, 2-3× lower dark current
- Testing separator with Ti electrodes now
  - Warping precludes use in Tevatron – useful only for R&D
- Prepared 6 new 180 kV supplies for new separators + spares
- Prepared 2 new 250 kV supplies for teststand use

Separator conditioning plot



O. Prokofiev

Conditioning at higher voltages decreased spark rate (10 kV up → spark rate down ~ 10 times)

Expected spark rate at 150 kV for separators conditioned at 180 kV will be less than 1 spark per year or about 3 order of magnitude less in comparing with traditional separator conditioned just at 150 kV.

Shutdown Work

Work Highlights in 2006 Shutdown

- Fix known cold leaks (F4, E2, A3, B4)
- Replace poppets on He Kautzky valves (≈1200)
- Reshim remaining 228 dipoles
- Unroll magnets
  - Quads in D1, A3 > 5 mrad (misfiducialized in factory)
  - Various magnets > 1 mrad since 2004 shutdown
- Replace 3 separators @ A49
- Install new separators @ A17, B48 (1 each)
- Install TEL-2 + repair TEL-1
- Pull cables for new sextupole circuits (chromatic compensation)
- Complete IPM installation
- Install new crystal collimator
- Infrastructure maintenance (feeders, cryo, etc.)

Post-Shutdown Tasks

- Recommission with beam…lots of changes
  - Adjust coupling following the dipole reshimming, unrolls
  - Implement new helices for injection and HEP
- Adjust IP positions
  - Already aware of low-β quad + detector motion
- Commission TEL-2
- Continue commissioning of IPM and OTR
- Complete chromatic compensation (split sextupole circuits)
  - Finish constructing new power supplies
  - Connect new cables to sextupoles, run with existing settings
  - Machine studies to implement lattice corrections
- Commission new BLM electronics
- Conduct machine studies on new working points (1/2, 2/3)
- Deliver lots of luminosity to CDF and D0

Summary

- Overall a good year for Tevatron operations
  - Luminosity increases due to 28 cm β* and Recycler pbars
- New instrumentation commissioning completed/underway
  - BPM electronics, IPM, OTR,…
- Run II Upgrade projects nearing completion
  - Separators, TEL-2, survey/ alignment, dipole shimming…
- Attacking reliability issues
  - Repairing known cold leaks, replacing poppets, new BLM electronics
- Preparing for higher intensities + luminosity
  - New sextupole circuits for chromatic compensation
  - Investigating new working points
  - Progress on simulations
- Looking to maximize delivered luminosity to CDF & D0